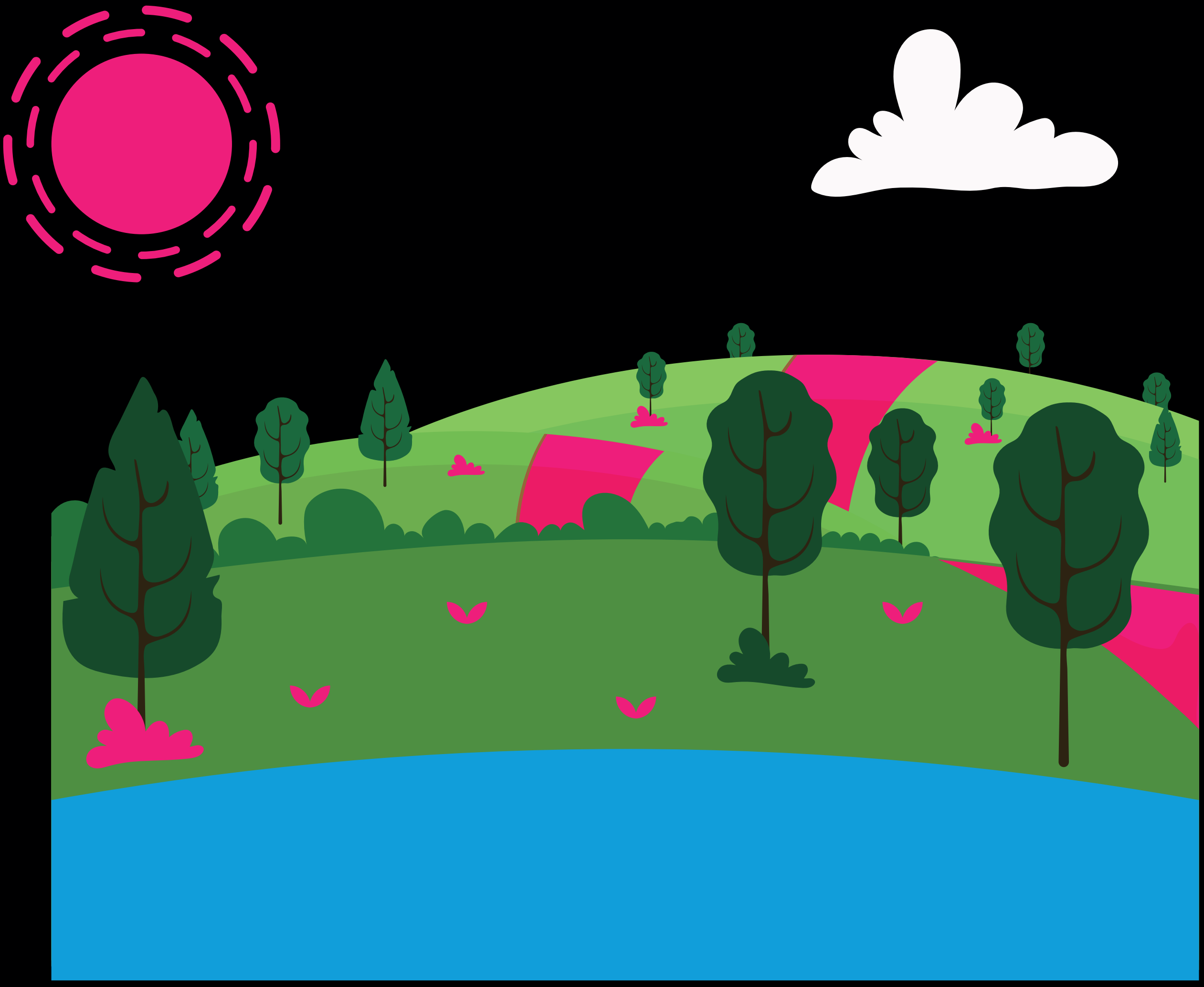
FUNDACIÓN AQUAE **TESIS**

Irrigation water management: an analysis using computable general equilibrium modelsl

UNIVERSIDAD DE ZARAGOZA
Doctor of Philosophy in Economics

CRISTINA SARASA FERNÁNDEZ



AQUAE
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IRRIGATION WATER MANAGEMENT: AN ANALYSIS USING COMPUTABLE GENERAL EQUILIBRIUM MODELS

Doctor of Philosophy in Economics

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“A model which took account of all the variegation
of reality would be of no more use than a map at
the scale of one to one”

Joan Robinson (1962 [152]): *Essays in the Theory of Economic Growth*, London: Macmillan

A mi familia

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A continuación presento un documento que recoge buena parte de mi trabajo como estudiante de Doctorado durante los últimos cuatro años. En estos años, he tenido la oportunidad de trabajar y vivir en un aprendizaje continuo. Pero ésto no hubiese sido posible sin la ayuda de muchas personas e instituciones, lo que me lleva a transmitir mi más sincero agradecimiento.

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"Elige un trabajo que te guste y no tendrás
que trabajar ni un día de tu vida"
Confucio (551 AC- 478 AC)

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Next, I present a document that includes much of my work as a PhD student for the past four years. During these years, I have had the chance of working and living in a state of continual learning. However, this would not have been possible without the help of many people and institutions, which leads me to give them my sincere thanks.

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> "Choose a job you love, and you will never
> have to work a day in your life".
> **Confucio (551 AC- 478 AC)**

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Introducción

Presentación y justificación

El agua, como recurso escaso y limitado, es imprescindible para la vida y acompaña al hombre en todas sus actividades sociales y económicas. Su uso produce diversas externalidades en múltiples ámbitos, lo que justifica el estudio económico, detallado y riguroso de la gestión del agua. La Directiva 2000/60/CE [64] (Directiva Marco del Agua o DMA en adelante) propone que se analicen, por lo menos, los usos del agua desglosados en industria, hogares y agricultura. Más aún, la DMA establece que los Estados miembros garanticen *"que la política de precios del agua proporcione incentivos adecuados para que los usuarios utilicen de forma eficiente los recursos hídricos"*, y exige de estos que realicen *"los cálculos pertinentes necesarios tomando en consideración los pronósticos a largo plazo de la oferta y la demanda de agua en la demarcación hidrográfica"*. (DMA 2000/60/CE, Anexo III, pág. 31/327 [64]).

De los usos anteriores: industria, hogares y agricultura, el más relevante es el uso del agua por el sector agrícola, que consume más del 80% de los recursos hídricos en España, MIMAN (2007 [131]). El principal protagonista del uso del agua en la agricultura es el regadío, cuya superficie en España cuenta con más de 3,6 millones de hectáreas que representan casi el 14% de la Superficie Agraria Útil (SAU) nacional y genera una producción que alcanza cerca del 60% del total de la producción agrícola española, MAPA (2006 [118], 2007 [119], 2009 [120]).

El regadío tiene una larga tradición histórica en España, especialmente en la región valenciana y en los Valles del Guadalquivir y del Ebro. Algunos de sus grandes canales tienen origen romano y fueron, posteriormente, mejorados y ampliados durante la época árabe y los siglos posteriores, existiendo desde hace mucho tiempo costumbres y leyes tradicionales que han regulado sus aspectos básicos. El agua ha sido considerada un *bien de la comunidad* y los propios regantes tenían instituciones locales para su regulación y mantenimiento e incluso sus propios tribunales, como por ejemplo, el Tribunal de las Aguas de Valencia, ver Del Campo García (1996 [50]).[1]

A lo largo del siglo XX, el creciente impacto medioambiental generado por la demanda de agua para regadío y la necesidad de modernizar el regadío para aumentar su eficiencia ha provocado un fuerte debate sobre sus costes y financiación. La respuesta dominante ha sido considerar que los costes de la modernización agraria deben ser abonados por los usuarios directos, principalmente regantes, en línea con la DMA y con la Ley de Aguas española. Se asume en esta respuesta que son ellos los que tienen la completa responsabilidad sobre los costes del uso del agua y de la modernización, olvidando que en el cálculo de los costes y beneficios del agua deberían considerarse también los costes y beneficios indirectos, ver Balairón-Pérez (2002 [15]).

Por otra parte, en los últimos años la planificación hidrológica en España ha incorporado muchos de los instrumentos propios del análisis económico: estimaciones de los usos, evaluación de la productividad y eficiencias de uso, externalidades, impactos en el desarrollo y en las exportaciones, etc. Todo ello ha llevado al análisis de la oferta y demanda de agua y de sus tendencias, así como a la búsqueda de las técnicas para incrementar la productividad y de las políticas necesarias para lograr la sostenibilidad y calidad del recurso, ver Maestu y Villar (2007 [114]).

Bajo este marco general y estos objetivos, en esta Tesis se trabaja sobre el diseño de estrategias de política económica regional, y se aplican a la gestión del agua de riego en la provincia de Huesca. La justificación de la elección de la provincia de Huesca se centra en la disponibilidad de los datos y en el hecho de que en ella se sitúa la agrupación de comunidades de regantes mayor de Aragón y de España, que abarca más de 127.000 hectáreas, en concreto, la Comunidad General de Riegos del Alto Aragón (CGRAA en adelante) que incluye a 58 comunidades ordinarias. Esta comunidad por sus características y dimensión es muy representativa del regadío del Valle del Ebro. Esta Tesis es por tanto un pequeño paso en el desarrollo de análisis regionales sobre el agua que, como señala Cardenete (2009 [42]), está siendo uno de los pasos más importantes del análisis regional de los últimos años. Más aún, la regionalización del

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[1] Este Tribunal fue estudiado por la premio Nobel de economía del año 2009, Elionor Ostrom en su obra "*El gobierno de los comunes. La evolución de las instituciones de acción colectiva*" (2000 [137], pág.121-137). Más aún, en 2009 este Tribunal fue designado Patrimonio Cultural Inmaterial de la Humanidad.

análisis es una de las mejoras más relevantes gracias a los recientes avances metodológicos (McGregor *et al.*, 2010 [129]; Partridge y Rickman, 2010 [140]).

Una vez definido el tema de la Tesis, la siguiente cuestión que uno se plantea es la metodología con la que se va a abordar. Recordemos que los economistas siempre hemos querido formular modelos que representen el conjunto de una economía concreta y que nos permitan prever todos los efectos de las políticas económicas aplicadas. En esta línea, esta Tesis se encuadra dentro de la teoría del equilibrio general aplicado o computable. Un modelo de equilibrio general aplicado (MEGA) es un conjunto de ecuaciones numéricas que capturan las características y el funcionamiento general de una economía, y que permite medir tanto los efectos directos como indirectos de las distintas alternativas de política económica así como los cambios en el comportamiento de los agentes económicos. Como destaca Gómez Gómez-Plana (2005 [84]), una de las virtudes de estos modelos es su capacidad para mostrar las consecuencias que un cambio puntual en una variable o en un sector puede tener en el conjunto de la economía.

La justificación para utilizar este tipo de modelos se basa en sus múltiples posibilidades de aplicación en distintos campos de investigación: política fiscal, comercial, migratoria, interregional, agraria, estabilización, gestión medioambiental, o en el análisis de la competencia imperfecta.[2] Esto hace que sean una herramienta útil y que una vez obtenido el modelo se puedan realizar diversas simulaciones de política económica. Más aún, usando modelos dinámicos, se pueden realizar predicciones a medio y largo plazo. En los últimos años, se ha generado un interés creciente por las aplicaciones de estos modelos para la resolución de problemas medioambientales o ecológicos. En este ámbito se sitúa este trabajo de investigación, que se centra, principalmente, en la gestión del agua.

En concreto, las aplicaciones empíricas que se desarrollan en los capítulos de la Tesis se encuadran en dos problemáticas, que se concretarán a nivel regional: la corresponsabilidad social en el uso del agua y en el reparto de costes; y el desarrollo de estrategias que permitan mitigar en el largo plazo los efectos económicos de las sequías y diseñar bajo éstas una senda de crecimiento económico.

La primera aplicación empírica requiere la elaboración de un modelo de equilibrio general aplicado estático, que se desarrollará siguiendo el modelo del Instituto

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[2] En Cardenete (2009 [42]) se pueden ver en detalle algunos de los distintos trabajos realizados en cada uno de los campos de investigación.

Internacional de Investigación sobre Políticas Alimentarias, o *International Food Policiy Research Institute* (IFPRI), ver Löfgren *et al*. (2002 [111]) como guía. El motivo para utilizar este modelo es su capacidad para responder y reaccionar a multitud de situaciones económicas, mostrando una gran potencialidad y flexibilidad. Hasta la fecha, se han realizado multitud de trabajos que lo utilizan para diferentes economías a nivel nacional y regional con distintos objetivos. Ejemplo de ello son los trabajos de Bednaříková y Doucha (2009 [21]) para dos economías locales en la República Checa, Psaltopoulos *et al*. (2011 [148]) para varias economías locales en Grecia y en la República Checa, Baas y Brücker (2010 [11]) para las economías de Alemania y Reino Unido, Banerjee y Alavalapati (2009 [18]) para la economía de Brasil, y Ahmed y Peerlings (2009 [5) para la economía de Bangladés.

La segunda aplicación empírica requiere el desarrollo de un modelo dinámico de equilibrio general aplicado que nos permita evaluar los efectos económicos a largo plazo de distintas predicciones y medidas de política económica. Como Baldwin y François (1999 [16], pág.1) señalan *"Los procesos económicos son dinámicos. El stock de capital humano, físico y de conocimiento cambia a lo largo del tiempo, al igual que el stock de recursos naturales. La gente y el capital emigran, la población crece y las tasas de inversión cambian."* Además, dado que el reto del agua es un asunto del largo plazo, los modelos dinámicos pueden ayudarnos a analizar la gestión del agua aportando información sobre los futuros impactos económicos. Se construirá para ello dos modelos dinámicos de equilibrio general aplicado, que serán resueltos como problema de complementariedad mixta mediante el Mathematic Programming System for General Equilibrium Analysis (MPSGE), ver Markusen y Rutherford (2004 [122]). La utilización de este sistema de lenguaje permite incluir la dinámica del modelo con mayor facilidad así como otras especificaciones concretas requeridas para el diseño de las políticas simuladas. Más aún, la incorporación de elementos estocásticos en un modelo de equilibrio general aplicado es también factible con este lenguaje, lo que nos permitirá tener en cuenta posibles incertidumbres que pueden afectar a la gestión del agua.

Objetivos y estructura de la Tesis

Uno de los objetivos centrales de esta Tesis es responder a una cuestión general dentro del marco planteado: ¿son los modelos de equilibrio general aplicado una herramienta útil para abordar los problemas económicos de la gestión del agua de riego y servir de guía a los responsables de estas políticas?

Esta pregunta es planteada teniendo en mente la problemática actual del agua para riego. Para poder hacer un análisis en profundidad se requiere, en primer lugar, poseer una buena información de la situación hídrica de la zona a analizar que permita ajustar los modelos y responder a problemas reales. Por ello, el **primer objetivo** de la tesis que se aborda en el primer capítulo es analizar la situación hídrica de la Comunidad General de Riegos del Alto Aragón durante la primera década del siglo XXI, así como las características principales de su gestión y uso del agua, estimando usos, niveles de eficiencia, rentabilidades, consumos efectivos, etc. Las comunidades de riegos, al estar formadas por los propios regantes que son los usuarios directos del agua a través del regadío, tienen un papel relevante en la gestión real del agua y en cualquier política que busque una orientación hacia el ahorro, la eficiencia y la conservación del recurso, y son en este caso los que suministran mucha de la información hídrica y económica utilizada para la investigación.

Por ello, la principal pregunta que se trata de responder en el primer capítulo es, ¿tiene la CGRAA dotación de agua suficiente para abordar la modernización, sus costes correspondientes, y la consolidación productiva de los próximos años? Por otro lado, se trata también de aportar información relevante sobre la situación del regadío actual en la CGRAA y su nivel de modernización, información que permitirá a los responsables técnicos y políticos de la gestión del agua la toma de decisiones y la discusión sobre los usos presentes y futuros del agua en la zona. El análisis de los recursos hídricos de una región a lo largo de un periodo determinado permite comprender las actuaciones pasadas y presentes de los agentes económicos y observar mejor la realidad económica.

Una vez planteados el marco y los problemas económicos a los que nos enfrentamos, el **siguiente objetivo** es el aprendizaje y selección de la metodología con la que se va a trabajar a lo largo de la Tesis. Para ello, en el segundo capítulo se presenta la metodología de los modelos de equilibrio general aplicado. En particular, se desarrolla en mayor detalle el modelo dinámico recursivo construido para las simulaciones del capítulo cuarto. No obstante, se exponen también las principales características del modelo estático usado en el capítulo tercero.

El **tercer objetivo** de la tesis, que se aborda en el tercer capítulo, es la aproximación a los efectos de una mayor corresponsabilidad social en el uso del agua para riego, todo ello a través del reparto de los costes necesarios para modernizar el regadío y mejorar la eficiencia de sus usos. Esta modernización es además necesaria para incrementar la productividad agraria, lo que es hoy en día necesario para mantener la actividad agraria con los niveles de agua disponibles, y para competir en los mercados internacionales.

El trabajo de este capítulo se sitúa en el marco de la actual investigación internacional sobre la corresponsabilidad de los impactos medioambientales, que ha sido especialmente aplicada a las emisiones de CO_2, y que ha permitido comprender mejor los flujos transfronterizos de CO_2 asociados a las importaciones y exportaciones, ver entre otros trabajos los de Munksgaard y Pedersen (2001 [133]), Peters y Hertwich (2006 [141]), Cadarso *et al*. (2009 [38]) y Lenzen *et al*. (2007 [107]). Este tipo de análisis es extensible a cualquier recurso natural, y en la Tesis se plantea aplicarlo al agua, analizando tanto sus usos en una región española, como las importaciones y exportaciones de agua de la región asociadas a su comercio exterior. Este trabajo supone una investigación novedosa y pionera en la gestión del agua, ya que mediante modelos de equilibrio general aplicado, tiene en cuenta para sus análisis a todos los usuarios, ya sean directos, indirectos o finales.

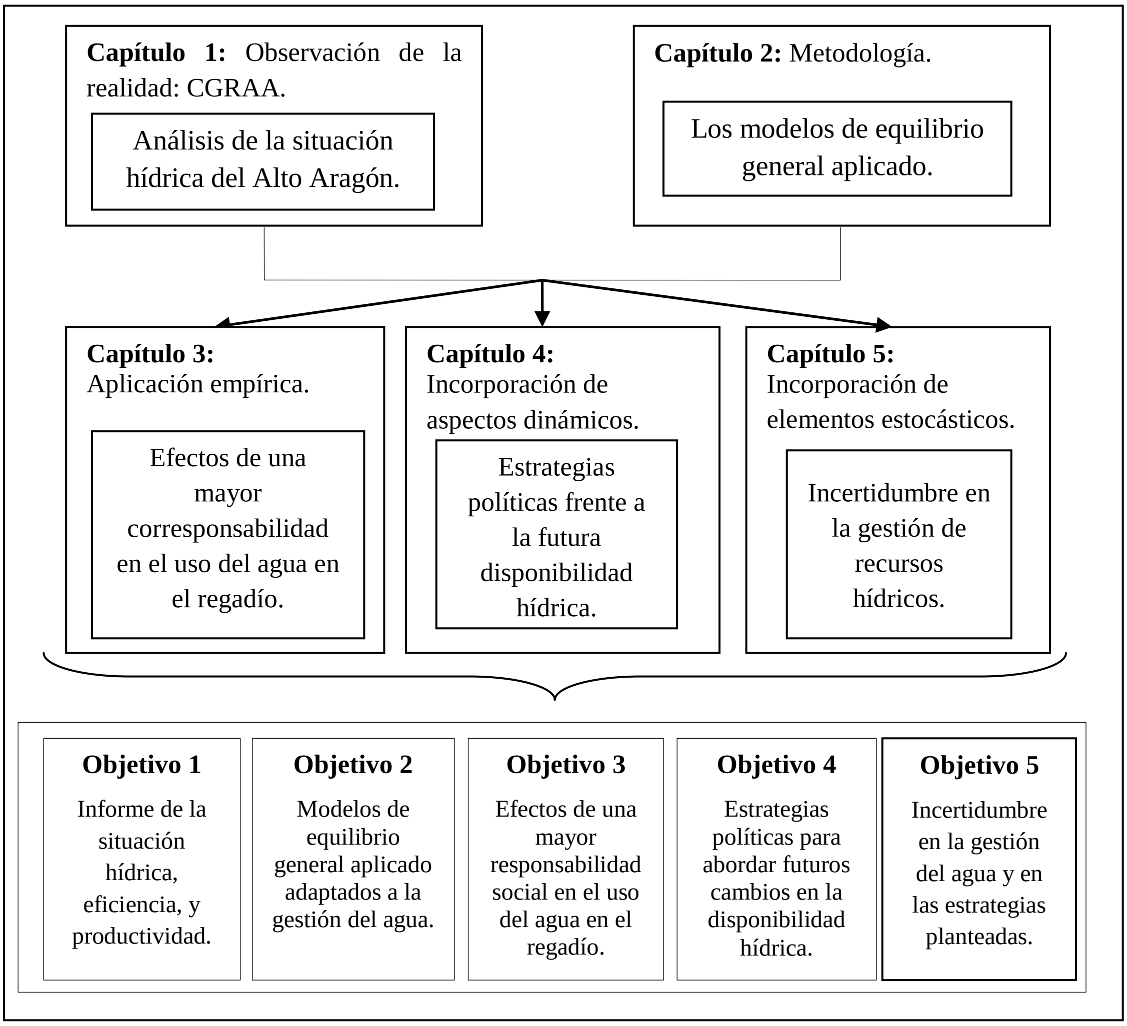
El **cuarto objetivo** de la Tesis se apoya en el modelo dinámico desarrollado en el segundo capítulo, abordando cuestiones que surgen tras el análisis de la evolución de los últimos años de los recursos hídricos (sequías hídricas), y de la transformación de las tecnologías de cultivo y de usos hídricos observados en la CGRAA y analizados en el primer capítulo. Por ello, el capítulo cuarto considera predicciones a largo plazo de la evolución de los recursos hídricos, teniendo en cuenta las limitaciones en el crecimiento de los recursos naturales, y analiza estrategias de política económica que permitan mitigar los impactos negativos y alcanzar una senda sostenible de crecimiento económico.

Las estrategias simuladas incorporan mejoras tecnológicas en el regadío, evaluando distintos tipos de progreso tecnológico, y apuntan directrices sobre cómo debe producirse el cambio tecnológico en el regadío. Además del cambio tecnológico, el marco institucional juega un importante papel frente a las restricciones de recursos hídricos. Por ello, teniendo en consideración la DMA que señala la recuperación de los costes como un objetivo central, se consideran también distintas estrategias que combinan políticas de precios y mejoras tecnológicas. Las principales preguntas a responder con todas estas estrategias son: ¿sería posible alcanzar una senda de crecimiento económico, en un marco de sequías, mediante estrategias que introduzcan mejoras tecnológicas? ¿Cómo debe ser el cambio tecnológico en la agricultura de regadío? ¿Podría ser decisiva una política de precios de agua para el regadío frente a la escasez del recurso?

Finalmente, el **último objetivo** de la tesis y que se desarrolla en su quinto capítulo, plantea una posible mejora de los resultados mediante la incorporación de elementos estocásticos, que permitan abordar la incertidumbre y evaluar la robustez de los resultados obtenidos con el modelo determinista del capítulo cuarto. Bajo este marco, se abordan diversas situaciones de incertidumbre: predicción de la futura disponibilidad de agua; tiempo en que una política de modernización de regadío consigue alcanzar un nivel de eficiencia avanzado en el uso del agua; y análisis de sensibilidad de los parámetros más relevantes.

Agrupando los objetivos expuestos, la siguiente figura muestra un esquema de la estructura de la Tesis, que pretende visualizar el orden en el que va a ser desarrollada para alcanzar cada uno de los objetivos planteados. En resumen, tras esta introducción un primer capítulo descriptivo analiza la situación hídrica del Alto Aragón, lo que permite situar al lector y comprender mejor el análisis y evolución de los recursos hídricos proporcionando información que servirá de guía para el resto de capítulos. El segundo capítulo presenta la metodología con la que se va a trabajar a lo largo de la Tesis. A continuación se presentan tres aplicaciones empíricas. El capítulo tercero aborda la corresponsabilidad de los distintos usuarios en el uso de agua de regadío. El capítulo cuarto examina distintas estrategias que incorporan mejoras tecnológicas en el regadío para hacer frente a restricciones de agua. El capítulo quinto incluye incertidumbre y aleatoriedad en los fenómenos planteados en el capítulo anterior. Y finalmente, se cierra con las principales conclusiones y algunas reflexiones finales que nos llevarán a proponer futuras líneas de investigación.

Figura 0.1. **Esquema de la estructura de la Tesis**



Fuente: Elaboración propia.

Introduction

Presentation and Justification

Water is a scarce and limited resource. It is essential for life and it accompanies man in all of his social and economic activities. It produces various externalities in numerous fields, which in itself justifies the economic detailed, exact study of water management from an economic standpoint. European Directive 2000/60/EC [64] (the Water Framework Directive or WFD) proposes analysis of at least the use of water in industry, households and agriculture. Moreover, the WFD requires Member States to ensure, *"that water pricing policies provide adequate incentives for users to use water resources efficiently"* and requires that, *"the necessary relevant calculations are carried out based on the long-term forecasts of supply and demand for water in the river basin"*, (WFD 2000/60/EC, Annex III, page 31/327 [64]).

Of the uses mentioned above (industry, households and agriculture), the most relevant is agriculture, which uses more than 80% of water resources in Spain, MIMAN (2007 [131]). The main use of water in agriculture is for irrigation, and Spain has more than 3.6 million hectares of farmland, which represents nearly 14% of the Utilised Agricultural Area (UAA) and generates about 60% of the country's total Agricultural production, MAPA (2006 [118], 2007 [119], 2009 [120]).

Irrigation has a long tradition in Spain, especially in the Valencia region and the Guadalquivir and Ebro valleys. Some of the larger canals have Roman origins and were, subsequently, improved and expanded during the Moorish period. This process continued in later centuries wherever local customs and traditional laws, some very ancient, regulated the basic aspects of water use. Water is considered a *common good* and farmers themselves created local institutions to regulate and maintain irrigation infrastructure, including their special courts like the *Tribunal de las Aguas* or Water Tribunal of Valencia (see Del Campo García, 1996 [50]).[3]

Throughout the twentieth century, the growing environmental impact caused by demand for irrigation water and the need to modernise irrigation systems and increase efficiency provoked heated debate over the issues of costs and funding. The principal conclusion, enshrined in the WFD and the Spanish Water Act, was that direct users (mainly irrigators) should pay the costs of agricultural modernization, thus making them fully liable for the costs of water use and modernization. However, this approach ignores the fact that indirect costs and benefits must also be considered in the calculation of water costs and benefits (see Balairón-Pérez, 2002 [15]).

Meanwhile many new tools for economic analysis have been brought to bear on water resource planning in Spain in recent years, including usage estimates, assessment of productivity and efficiency of use, externalities, the impact on development and exports, etc. All of this has led to an analysis based on the supply and demand for water and the related trends, at the same time encouraging the search for techniques to raise productivity and for viable policy options to achieve sustainability and ensure water quality (see Maestu and Villar, 2007 [114]).

In this general context and given these objectives, this thesis will look at strategy designs in regional economic policy and apply them to irrigation water management in Huesca province, which was chosen based on the availability of data and because it is one of the home provinces (together with Zaragoza) of the Upper Aragon Irrigation Scheme (CGRAA in its Spanish acronym), Spain’s largest such system covering more than 127,000 hectares and including 58 sub-schemes. Given its characteristics and size, the CGRAA is highly representative of irrigation in the Ebro Valley. This thesis is therefore a modest contribution to the regional analysis of water issues, one of the key advances made in the field of regional analysis in recent years, according to Cardenete (2009 [42]). Moreover, this regionalisation in the study of water issues has progressed significantly thanks to recent methodological proposals (McGregor *et al*., 2010 [129]; Partridge and Rickman, 2010 [140]).

Having defined the topic of this thesis, let us turn to the methodology used. Economists have, of course, always sought to develop models which represent the

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[3] The *Tribunal de las Aguas* was studied by Nobel Economics Prize winner Elinor Ostrom in 2009 in her book, “Governing the Commons: The Evolution of Institutions for Collective Action” (2000 [137], pages 121-137), and it was declared an Intangible Cultural Heritage of Humanity in 2009.

whole of a specific economy and allow prediction of all effects of economic policies applied, and this thesis is framed by the Computable General Equilibrium Theory. A Computable General Equilibrium (CGE) model is a set of numerical equations which capture the characteristics and general working of an economy and measure both the direct and indirect effects of different policy alternatives, as well as changes in the behaviour of economic agents. As Gómez Gómez-Plana explains (2005 [84]), one of the virtues of these models is their ability to show the consequences that any specific change in a variable or sector can have on the overall economy.

The rationale for using a model of this type is based on its applicability in numerous different research fields, including tax policy, trade, migration, interregional systems, agricultural policy, land stabilisation and environmental management, and in the analysis of imperfect competition.[4] This makes it a useful tool, and once the model has been specified it is possible to perform multiple simulations of economic policies. Moreover, dynamic models can be used to make medium and long-term forecasts. There has been a growing interest in applications of CGE models to solve environmental and ecological problems in recent years, and the present research belongs to this field, focusing mainly on water management.

Specifically, the empirical applications described in the following chapters of this thesis relate to two problems, which are considered at the regional level. These are the shared social responsibility inherent in water use and cost sharing; and the design and development of strategies to mitigate the long-term economic effects of water constraints and assure economic growth.

The first empirical application requires the specification of a static Computable General Equilibrium model along the lines of the model developed by the *International Food Policy Research Institute* (IFPRI) (see Löfgren *et al.*, 2002 [112]). This model is used in view of its ability to respond and react to different economic situations, and its enormous potential and flexibility. It has been applied to date in a number of studies with diverse objectives carried out in different economies at both the national and regional levels. Examples include Bednaříková and Doucha (2009 [21]) for two local economies in the Czech Republic; Psaltopoulos *et al*. (2011 [148]) for local economies in Greece and the Czech Republic; Baas and Brücker (2010 [11]) for the economies of

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[4] Cardenete (2009 [42]) provides a detailed review of studies performed in each of these research fields.

Germany and the United Kingdom; Banerjee and Alavalapati (2009 [18]) for the economy of Brazil; and Ahmed and Peerlings (2009 [5]) for the Bangladeshi economy.

The second empirical application requires the development of a dynamic Computable General Equilibrium model allowing the evaluation of different long-term economic forecasts and economic policy measures. As Baldwin and François (1999 [16], page 1) argue, *"Economic processes are dynamic. Human, physical and knowledge capital stock change with time, the same as natural resources stock. People and capital emigrate, the population grows and investment rates change"*. Furthermore, given that the challenge of water is a long-term matter, dynamic models can help the study of water management by providing information about future economic impacts. Two dynamic Computable General Equilibrium models will be built for these purposes, which will be solved as a mixed complementarity problem by means of the Mathematic Programming System for General Equilibrium Analysis (MPSGE) (see Markusen and Rutherford, 2004 [122]). This programming language makes it easier to include the dynamic model and certain other specifications required for the design of simulated policies. Moreover, it allows incorporation of stochastic elements in the Computable General Equilibrium model, so that we may take into account possible uncertainties affecting water management.

Objectives and structure of the Thesis

One of the main objectives of this thesis is to answer a general question within the proposed framework: Are Computable General Equilibrium models a useful tool to tackle economic problems relating to irrigation water management, and do they serve as a guide for policy-makers?

This question is raised in view of the current problems surrounding water for irrigation. In order to make a thorough analysis it is necessary, in the first place, to have good information about the water situation in the subject area, allowing for adjustments to the models and responding to real problems. Therefore, the **first objective** of this thesis will begin by discussing the water situation in the Upper Aragon Irrigation Scheme in the first decade of the twenty-first century, as well as the main characteristics of the Scheme's management and use of water, efficiency levels, profitability, effective use, etc. Being formed by irrigators who are themselves direct users of irrigation water, Irrigation Schemes play a relevant role in water management and in the actual implementation of any policy that seeks savings, efficiency and conservation of the resource. In the case of the present research, moreover, they are the source of much of the economic and water information used.

The main question which the first chapter will try to answer is whether the CGRAA has sufficient water resources to tackle modernisation, defray the resulting water costs and consolidate gain in output over the coming years. It also provides key information about the current status of modernization in the Irrigation Scheme, which should prove invaluable for political and technical decision-makers and to fuel debate about the present and future uses of water in the area. The analysis of a region's water resources over a given period of time throws light on the past and present actions of economic agents and improves observation of the real economy.

After sketching the background and setting out the economic problems facing us, we will go on to discuss the methodology selected for use throughout this thesis as a **following objective**. To this end, the second chapter describes the methodology underlying Computable General Equilibrium models, focusing in particular to the dynamic recursive model used in the fourth chapter. However, the main characteristics of the static model used in the third chapter are dealt with.

The **third objective** of the thesis, dealt with in the third chapter, is to show the effects of greater shared social responsibility in the use of water for irrigation, through sharing of the necessary costs to modernise irrigation, improve efficiency and raise agricultural productivity, which will be a key factor if farmers are to maintain output while respecting available water levels and to compete successfully in international markets.

The work described in this chapter is based on current international research about shared responsibility for environmental impacts, in particular to CO_2 emissions, which has greatly improved our understanding of the cross-border flows of CO_2 associated with imports and exports (see among other studies of Munksgaard and Pedersen, 2001 [133]; Peters and Hertwich, 2006 [141]; Cadarso *et al*., 2009 [38]; and Lenzen *et al*., 2007 [107]). This type of analysis can be extended to any natural resource and it is applied here to water through an analysis of uses in one region of Spain, and of trade-related imports and exports of water. This work is a new avenue of research in the field of water management using Computable General Equilibrium models, which take into account all users, whether direct, indirect or final.

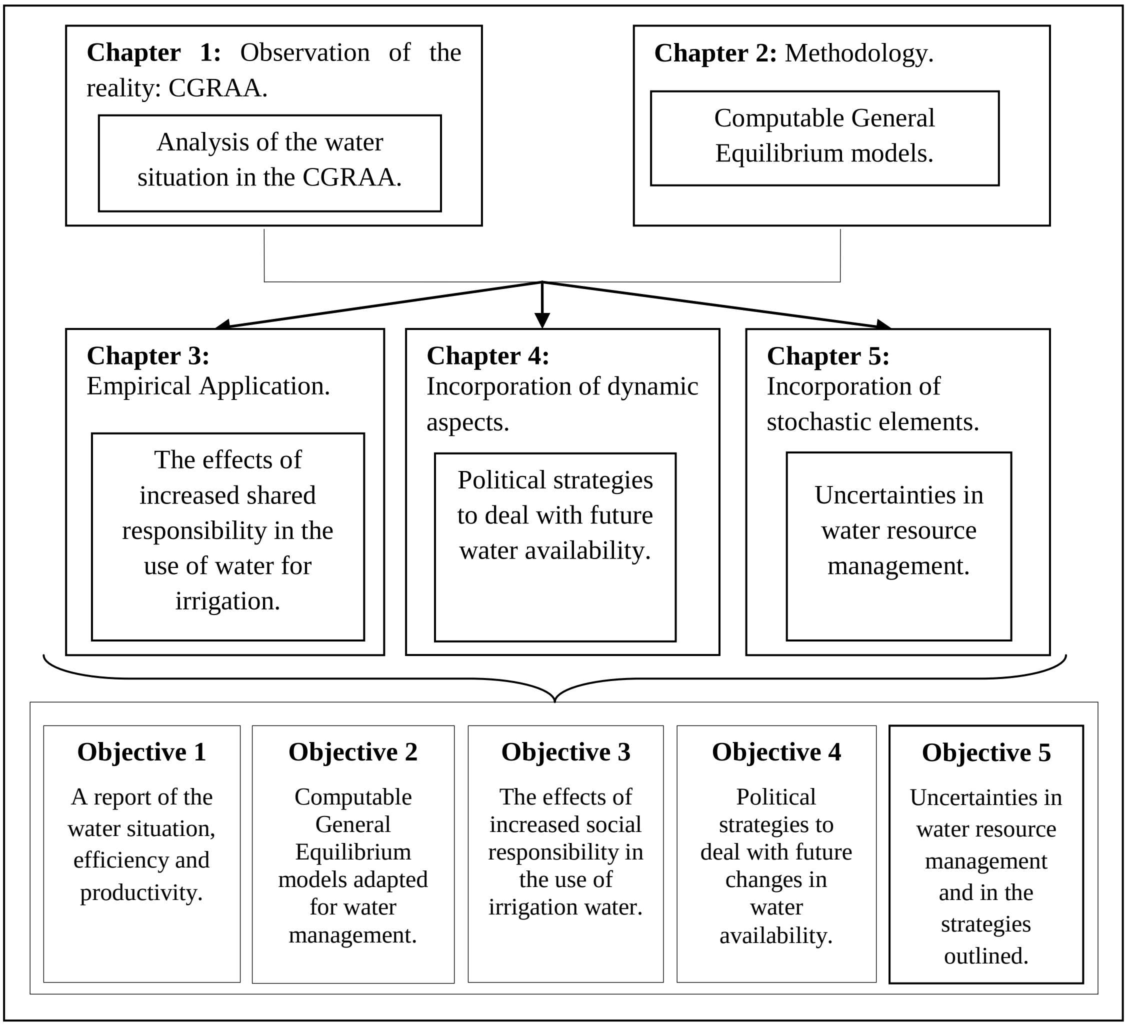
The **fourth objective** of the thesis is based on the dynamic model developed in the second chapter, addressing the questions raised by the analysis of drought in recent years, and the transformation of farming technologies and water uses observed in the CGRAA and analysed in the first chapter. The fourth chapter, then, considers long-term forecasts relating to the evolution of water resources, taking into account growth limitations on natural resources and analysing the political and economic strategies that might mitigate negative impacts and achieve a sustainable path of economic growth.

The simulated strategies incorporate better irrigation technologies, evaluating different types of technological progress and suggesting guidelines for successful technological change in irrigation. The institutional framework too plays an important role in the restriction of water resources. Therefore, taking into account the WFD, which establishes cost recovery as a key objective, the different strategies that combine price policies and better technology are also considered. The main questions with regard to these strategies are: Would it be possible to achieve economic growth in a context of drought by means of strategies to introduce better technology? What are the technological changes needed in irrigated agriculture? Could a policy governing the pricing of irrigation water be decisive, given the scarcity of the resource?

The **last objective** of the thesis is dealt with in the fifth chapter, which looks at the possibility of improving the results obtained from the study by including stochastic elements to account for uncertainty and evaluate the robustness of the results obtained from the determinist model described and applied in the fourth chapter. Under this structure, numerous situations of uncertainty are addressed, including predictions about the future availability of water, the time it takes for a policy of irrigation modernisation to achieve an advanced level of efficiency in water use and a sensitivity analysis of the most relevant parameters.

Grouping these objectives, the following structure chart outlines the structure of the thesis, showing the order in which each of the objectives mentioned will be dealt with and discussed. To sum up, after this introduction, a first descriptive chapter describes the water situation in the CGRAA, providing the reader with a better understanding of the analysis and the evolution of water resources with key information which will serve as a guide for the rest of the chapters. The second chapter deals with the methodology that will be used throughout the thesis. Next, three empirical applications are presented. The third chapter deals with the shared responsibility of different users in the use of irrigation water. The fourth chapter examines different strategies incorporating improved technology to deal with water restrictions. The fifth chapter deals with uncertainty and randomness in the phenomena described in chapter four. The thesis ends with the main conclusions and some final reflections and proposals for future areas of research.

Figure 0.1. **Schematic Structure of the Thesis**



Source: Own work.

Chapter 1

Analysis of the water situation in *Upper Aragon*

1.1. Presentation: Materials and methods

The first chapter of the thesis, the core of which is the paper published in *Economía Agraria y Recursos Naturales* (Sánchez-Chóliz and Sarasa, 2013 [164]), presents a detailed analysis of the water and economic situation on which the next chapters will focus. This will allow us to share with the reader the key issues which motivated the work described in the following chapters. Moreover, valuable statistical information is provided in the appendix to the chapter, which could be used for future work and by other researchers.

To begin with, this chapter could not have been written without the initial statistical information provided by the Upper Aragon Irrigation Scheme on agricultural, urban and industrial water uses in each irrigation sub-scheme between 2001 and 2010, and the evolution of the total number of hectares and the number of hectares with high irrigation priority within each sub-scheme. This information is included in Tables A1, A2 and A3 of Appendix A of this chapter. The CGRAA also provided information on the current status of the modernization processes underway in each of the irrigation sub-schemes that make up the CGRAA (see Table A4 in Appendix A).

Secondly, we conducted an analysis of the distribution of the irrigated area by crop type in each irrigation sub-scheme. This distribution was obtained from the crop structure of the irrigated land belonging to each member village, as provided by the

DGA (2011a [57]). The distribution was applied to the number of irrigated hectares in each community presented in Tables A2 and A3 in Appendix A. The results for the period from 2001 to 2010 in the Monegros and Cinca areas are shown in Tables A5, A6 and A7 of Appendix A, together with the CGRAA totals.

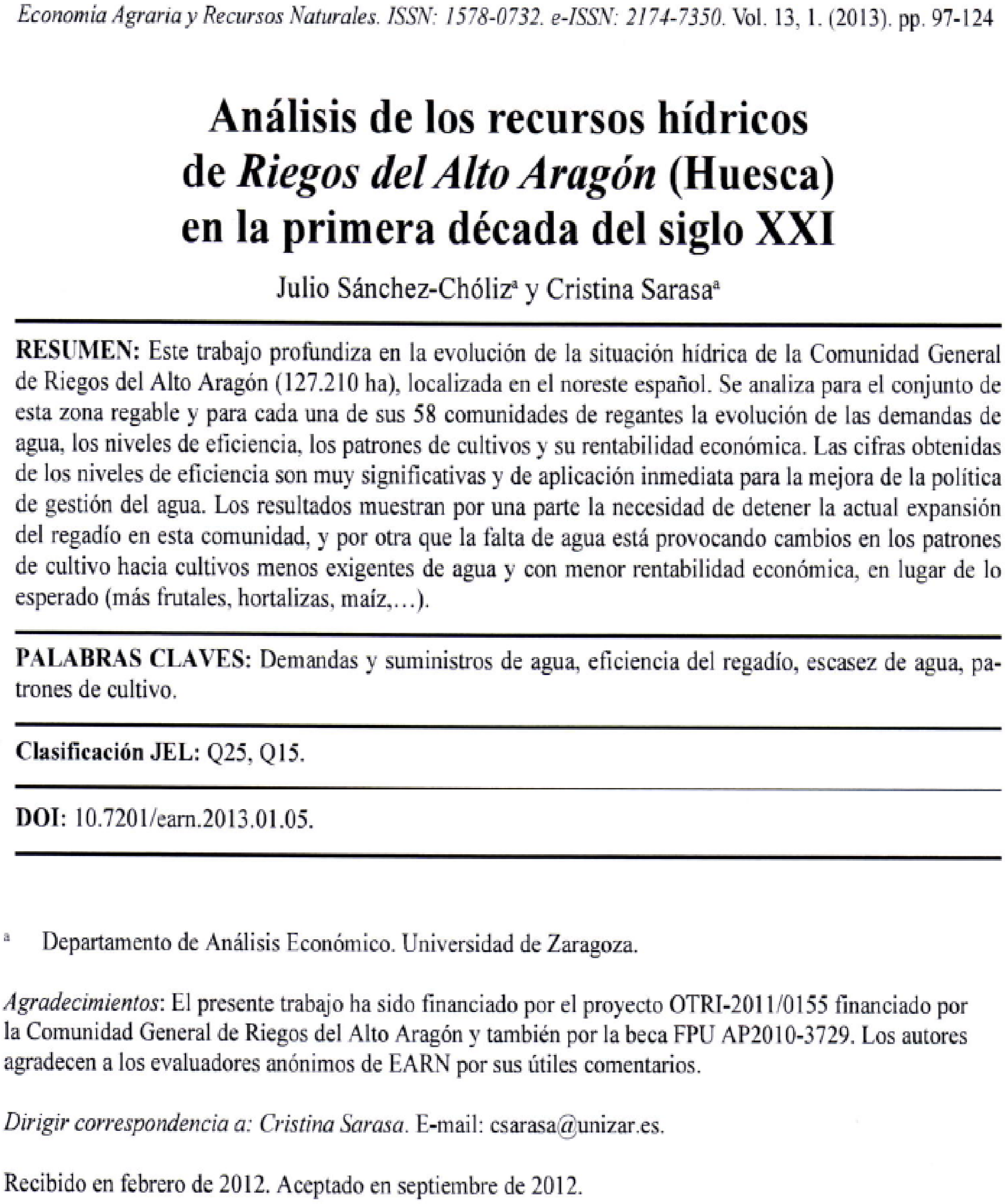
On the basis of the available material, we estimated and analysed the levels of efficiency. The total physical water consumption in each irrigation sub-scheme, defined as the additional volume of water which crops require, taking the estimated average rainfall in each area into account and without considering water runoff or deep percolation, can be obtained by multiplying crop hectares by the net water requirements of each crop listed. As we shall see, the comparison of total physical consumption in each sub-scheme with the volume of water supply from water storage for irrigation will then allow us to ascertain the level of total efficiency. Next, by comparing this volume with water application in the field, we can obtain the level of field application efficiency. These concepts are explained in the course this chapter.

Tables A8, A9 and A10 in Appendix A show the volume of water required by crops in the sub-schemes located in the Monegros and Cinca districts, and in the whole of the CGRAA, for the number of hectares with high irrigation priority. As it was expected, the volume of water required in the Monegros area is greater than that required in the Cinca area, because the former has more hectares under irrigation and more sub-schemes.

For those who are interested, an exhaustive and detailed analysis of the situation of each of the CGRAA’s member irrigation schemes will be found in Sánchez-Chóliz and Sarasa (2011 [163]). See also Map A1, which shows the location of each irrigation scheme in Appendix A.

In section 1.2, we present the work published in the review *Economía Agraria y Recursos Naturales* (Sánchez-Chóliz and Sarasa, 2013 [164]) with the original structure of sections and language. However, we have included some minor changes in the presentation for the purposes of harmonization with this thesis. We use the terms of “Table” and “Figure” instead of the Spanish “Cuadro” and “Gráfico”, keeping the table and figure orders of the thesis. Finally, the references of the work are included in the bibliography section. The English version of this work (section 1.2) is provided in section 1.3.

1.2. Sánchez-Chóliz y Sarasa (2013): Análisis de los recursos hídricos de *Riegos del Alto Aragón* (Huesca) en la primera década del siglo XXI (*Spanish version*)



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Análisis de los recursos hídricos de *Riegos del Alto Aragón* (Huesca) en la primera década del siglo XXI

Julio Sánchez-Chóliz[a] y Cristina Sarasa[a]

RESUMEN: Este trabajo profundiza en la evolución de la situación hídrica de la Comunidad General de Riegos del Alto Aragón (127.210 ha), localizada en el noreste español. Se analiza para el conjunto de esta zona regable y para cada una de sus 58 comunidades de regantes la evolución de las demandas de agua, los niveles de eficiencia, los patrones de cultivos y su rentabilidad económica. Las cifras obtenidas de los niveles de eficiencia son muy significativas y de aplicación inmediata para la mejora de la política de gestión del agua. Los resultados muestran por una parte la necesidad de detener la actual expansión del regadío en esta comunidad, y por otra que la falta de agua está provocando cambios en los patrones de cultivo hacia cultivos menos exigentes de agua y con menor rentabilidad económica, en lugar de lo esperado (más frutales, hortalizas, maíz,…).

PALABRAS CLAVES: Demandas y suministros de agua, eficiencia del regadío, escasez de agua, patrones de cultivo.

Clasificación JEL: Q25, Q15.

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1.2.1. Introducción

A lo largo del siglo XX, la gestión del agua en el regadío español se ha caracterizado por un predominio de los modelos de oferta para satisfacer la demanda de los diversos usos posibles, así como por el aumento de la regulación y la capacidad para controlar el aprovechamiento de los recursos hídricos (Pinilla, 2008 [144]). Otra característica esencial de este siglo ha sido el rápido crecimiento de la superficie regada que ha pasado de aproximadamente 40 millones de hectáreas regadas en el mundo en 1900 a 274 millones en el año 2000 (Federico, 2005 [75]).

Esta expansión del regadío ha tenido un papel clave en el desarrollo y crecimiento de la agricultura española, especialmente desde los años 60, permitiendo el abastecimiento de alimentos básicos, la diversificación de alimentos y el aumento de la exportación de productos agrarios y agroalimentarios. Esto se ha debido en buena medida al incremento de la productividad agraria del regadío en España, que ha permitido que una población activa agraria cada vez menor pueda abastecer a una población urbana cada vez mayor (INE, 1965-1989 [97]). En concreto, una hectárea de regadío produce seis veces más que una hectárea de secano y genera una renta cuatro veces superior (MARM, 2008 [126]).

La cuenca del Ebro es la cuenca hidrográfica más importante de España y representa un 17% de su territorio, siendo España uno de los países más importantes del mundo por su superficie regada.[5] En esta cuenca el ritmo de construcción de infraestructuras hidráulicas así como la expansión del regadío se anticipó algo a otras partes de España, pero la desaceleración en el crecimiento del regadío en las dos últimas décadas del siglo XX ha coincidido con la del resto de España y la tendencia internacional (Pinilla, 2008 [144]). Dentro de la cuenca del Ebro, el regadío de la provincia de Huesca cuenta con más de 200.000 hectáreas que representan casi el 40% de la Superficie Agraria Útil (SAU) de Huesca y el 6% de la superficie agraria de regadío en España (MARM, 2010 [127]). La producción que genera el regadío de Huesca alcanza más del 80% del total de la producción agrícola de la provincia (DGA, 2009 [56]).

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[5] En 2009, España era el décimo cuarto país del mundo por hectáreas regadas (FAO, 2009 [73]). Su regadío representa el 1,34% del regadío total mundial.

En la actualidad y desde las últimas décadas del siglo XX, se ha producido un debate sobre la continuidad del modelo de crecimiento del regadío, expansión sistemática de la oferta de agua, planteándose la incorporación de otros criterios como la eficiencia, el análisis coste-beneficio de las nuevas intervenciones planeadas y la gestión de la demanda (véase Pinilla, 2008 [144]; Gleick, 2000 [81]; Schoengeld y Zibelman, 2007 [169]). Trabajos como el de Barros *et al*. (2011 [20]) señalan que en España se dispone de poca información sobre la evolución de los niveles de eficiencia obtenidos en las distintas comunidades de riegos así como de los patrones de cultivo principales.

En esta línea, este trabajo pretende abordar dos objetivos simultáneamente: analizar la situación hídrica de uno de los más ambiciosos proyectos de regadío en España (véase Silvestre y Clar, 2010 [172]), en concreto, la Comunidad General de Riegos del Alto Aragón (en adelante, CGRAA) durante la primera década del siglo XXI, así como las características principales de su gestión y niveles de eficiencia en el uso del agua. La gestión óptima del agua es especialmente importante para sus comunidades de regantes, ya que las fuertes inversiones necesarias para la modernización de sus sistemas de riegos y la mejora de su productividad, sólo tienen sentido si pueden recuperarse a través de la producción y si hay disponibilidad y garantía de agua suficiente. Por ello tratamos por una parte de responder sobre todo a esta pregunta, ¿tiene la CGRAA dotación de agua suficiente para abordar la modernización, sus costes correspondientes, y la consolidación productiva de los próximos años?; y por otra, de aportar información relevante sobre la situación del regadío actual en la CGRAA y su nivel de modernización, información que permitirá a los responsables técnicos y políticos de la gestión del agua la toma de decisiones y la discusión sobre los usos presentes y futuros del agua en la zona.

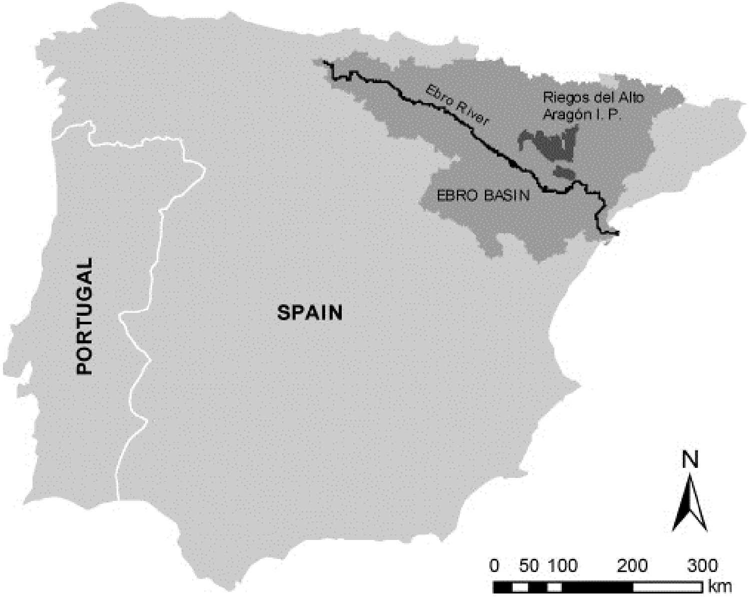
En el Alto Aragón se han realizado estudios previos sobre los niveles de eficiencia en el regadío en determinadas comunidades de riegos como son los trabajos de Tedeschi *et al*. (2001 [177]) para 1.000 hectáreas en la zona de Monegros II, García *et al*. (2009 [79]) para una superficie de 95 hectáreas, o Playán *et al*. (2000 [145]) para la comunidad de riegos de Almudévar perteneciente a la CGRAA. Este trabajo de investigación pretende ir más lejos y analizar los usos y eficiencias del conjunto de la CGRAA, que abarca más de 125.000 hectáreas regables, y de cada una de sus 58 comunidades, utilizando para ello información reciente que nos permite ampliar las conclusiones de los trabajos previos a la primera década del siglo XXI.

Para llevar a cabo esto, tras esta introducción se continúa con una breve presentación de la CGRAA, que permite comprender mejor el análisis y evolución de sus demandas de agua, comentando también las fuentes de datos que se van a utilizar y su origen. En la sección tercera, apoyándonos en los datos anteriores, se definen y obtienen sus niveles de eficiencia en el uso del agua, lo que nos permite cuantificar las necesidades hídricas de los cultivos y estimar los posibles déficits. En la cuarta se examina la evolución de la estructura de cultivos y la rentabilidad de los principales cultivos. Finalmente se cierra con las principales conclusiones y algunas reflexiones finales, que pueden ayudar al diseño de nuevas medidas para la gestión del agua.

1.2.2. La demanda de agua en el Alto Aragón: la CGRAA

La CGRAA es actualmente un sistema de regadío con más de 125.000 hectáreas de cultivo, que abastece también a numerosas localidades de las provincias de Huesca y Zaragoza y a diez polígonos industriales. Esta comunidad general agrupa a 58 comunidades de regantes, que se encuentran situadas principalmente entre el Canal de Monegros y el Canal del Cinca. De acuerdo con los planes existentes y aprobados, la superficie final prevista de la CGRAA podría llegar a las 185.000 hectáreas, a las que cabría añadir en un futuro la Hoya de Huesca, los regadíos de Alconadre y la acequia de Leciñena, lo que llevaría a una cifra aproximada de 200.000 hectáreas, superficie difícilmente alcanzable como veremos con las disponibilidades actuales de agua y con las regulaciones previstas. No obstante, esta comunidad es ya actualmente el mayor sistema de regadío de la Cuenca del Ebro y también de todo el territorio español (Mapa 1.1).

MAPA 1.1. **Comunidad General de Riegos del Alto Aragón**



Fuente: Lecina *et al*. (2010b [105]).

Las estimaciones que vamos a presentar, tanto para la CGRAA como para cada una de sus comunidades sólo han sido posibles porque hemos tenido a nuestra disposición datos fiables por comunidades y años, facilitados muchos de ellos por la propia CGRAA que los elaboró ex profeso. En concreto, los consumos reales de cada comunidad a lo largo de los 10 años para los distintos usos del agua (riego, industria y abastecimiento), los suministros de agua regulada realizados por la Confederación Hidrográfica del Ebro (en adelante, CHE) a la CGRAA, el estado actual de las modernizaciones en cada comunidad e información cualificada sobre los cultivos fueron facilitados directamente por la propia CGRAA. Las necesidades hídricas se extrajeron del trabajo de Martínez-Cob *et al*. (1998 [128]). Finalmente, se utilizó también la estructura de cultivos de regadío por municipios realizada por el Departamento de Agricultura y Alimentación del Gobierno de Aragón.[6]

Con parte de esta información se elaboró la Tabla 1.1, donde se presenta la situación actual del proceso de modernización en la CGRAA. Puede verse en esta tabla que 29.606 hectáreas fueron modernizadas cuando se transformaron en regadío y que 44.022 hectáreas se han modernizado recientemente o están finalizando el proceso. Por otra parte, el 18% de la superficie total posee acuerdos para comenzar los procesos de modernización. Todo esto supone que en los próximos años más del 76% de la

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[6] Por su utilidad para otros trabajos, los datos están a libre disposición del que lo desee y pueden descargarse en la dirección http://www.credenat.com/

superficie total de la CGRAA estará modernizada. A estas cifras hay que añadir además el 5% que posee alguna obra de modernización como balsas. Sin embargo, existe un 19% de la superficie total de la CGRAA que no se encuentra modernizada ni tiene acuerdos para hacerlo.

Tabla 1.1. **Situación de la superficie en modernización**

Estado	**Superficie (Has 2010)**	**%**
Modernizadas en el actual proceso	44.022	35%
Con acuerdo	23.057	18%
Modernizadas al transformarse en regadío	29.606	23%
Alguna obra (balsas o barranco)	6.304	5%
No modernizan	24.220	19%
TOTAL	**127.210**	**100%**

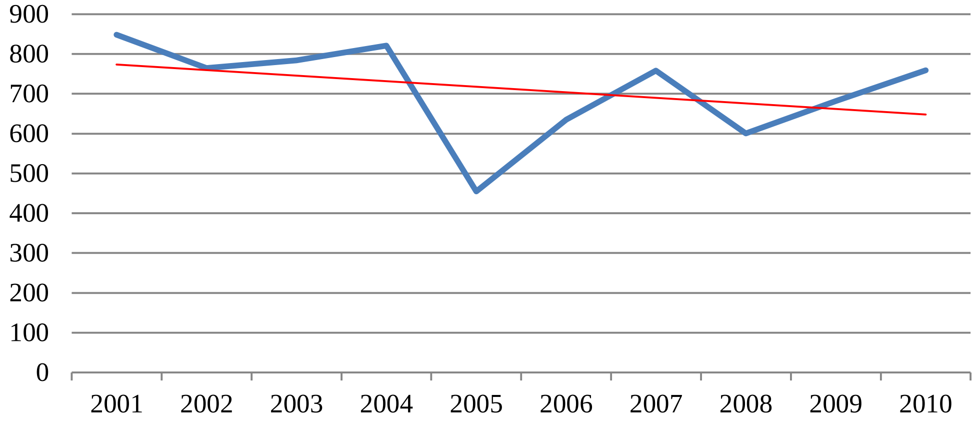
Fuente: CGRAA.

La modernización está siendo abordada individualmente por cada comunidad, teniendo un doble carácter. Por una parte la comunidad de regantes moderniza sus sistemas de distribución y regulación interior (acequias, balsas, bombeos, sistemas de control y distribución, etc.), y por otra cada comunero debe adecuar y amueblar su parcela. Estos últimos costes los asume íntegramente el regante y de los primeros, salvo un 15% del total que es financiado actualmente por la Unión Europea, el 85% restante lo debe pagar también el comunero directamente por dos vías: el 35% se paga como máximo en los 25 primeros años y el resto, el 50% lo pagará en el periodo del año 26 al 50. Esto hace que los procesos de modernización estén siendo muy gravosos para los regantes, representando los pagos corrientes porcentajes alrededor del 40% de los costes totales, cuando los pagos por cánones y tarifas del agua no superan el 10% (véase Cazcarro *et al*., 2011a [44] y 2011b [45]). A esto hay que añadir en esta última década las subidas de materias primas como los abonos, las sequías de 2005 y 2008, y los cambios en la subvenciones de la PAC.

No obstante, los criterios de pago aplicados en la modernización reciente, inspirados en los criterios de recuperación de costes de la Directiva Marco del Agua (DMA, 2000/60/CE [64]), aunque gravosos, han tenido también un aspecto muy positivo: los regantes enfrentados a mayores pagos por el agua y a otros costes crecientes, podían abandonar o modernizar sus explotaciones intensificando la producción, mejorando sus canales de comercialización e integrándose con los sectores de la industria agroalimentaria. Ésta ha sido la respuesta dominante en la CGRAA.

La Figura 1.1 muestra la evolución de las demandas de agua de las comunidades de regantes a lo largo de la primera década del siglo. En estos años, la CGRAA recibe en parcela, en media anual, alrededor de los 710,8 hm^3 de agua para riego (Tabla 1.2), cantidad similar a la recibida a finales del siglo anterior (Sánchez-Chóliz y Duarte, 2006 [161]). La Figura 1.1 muestra, no obstante, una preocupante tendencia decreciente, debida entre otros motivos a la revegetación en las cabeceras de los ríos (véase Bielsa *et al*., 2011 [25]), a los efectos del cambio climático y a la inexistencia de regulación plurianual en el sistema. En el año 2005 se observa una profunda caída del suministro de agua para riego hasta casi la mitad del año 2001 provocada por la sequía de ese año. Aunque el suministro de 2006 es mayor que en 2005, sigue estando por debajo de la media, que se supera en 2007. Pero de nuevo cae en 2008, manteniéndose en 2009 por debajo de la media.

Figura 1.1. **Evolución de la demanda en parcela para riego (Hm^3)**



Fuente: Elaboración propia con datos de la CGRAA.

El uso de agua para riego en la CGRAA representa casi el 98% de su total de usos. Sin embargo, en los últimos años, el peso del regadío va disminuyendo ligeramente al crecer los suministros que hace el sistema a las actividades industriales y a los abastecimientos de la zona (Tabla 1.2). En el año 2005, que es el año más seco en la zona desde que se comenzaron a hacer mediciones sistematizadas de lluvias en 1947 según la Agencia Estatal de Meteorología (AEMET, 2005 [2]), el volumen de demanda de agua para riego se vio notablemente reducido, mientras que la demanda de agua para industria y abastecimiento aumentó. Esto demuestra la mayor rigidez de la demanda industrial y urbana frente a la demanda agraria y fue posible también por los criterios de preferencia establecidos por la legislación para los abastecimientos urbanos frente al regadío.

En la Tabla 1.2 se muestra también la evolución del agua suministrada anualmente a la CGRAA por parte de la CHE desde sus embalses; el suministro medio ha sido de 847,7 hm³ de agua regulada, que han servido para regar las más de 115.000 hectáreas de pleno derecho del 2001, siendo más de 121.000 has en 2010. Si se contabilizan las hectáreas con riego en precario se llegan a las 127.210 hectáreas en el 2010. Como hemos visto, el volumen de agua suministrado muestra una tendencia ligeramente decreciente aunque no uniforme.

Tabla 1.2. **Demandas y suministros a la CGRAA**

Año	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	***Promedio***
Hectáreas pleno derecho (incluye Monegros II)	115.933	116.259	116.647	119.985	121.410	119.995	121.284	121.606	121.503	121.896	
Hectáreas totales	123.049	123.969	124.311	124.795	125.547	125.790	128.974	126.539	127.124	127.210	
Hm³ de demanda en salida de embalse	1.025,2	909,1	912,2	949,0	565,7	747,7	874,7	696,3	949,2	847,6	847,7
Hm³ de demanda en destino para abastecimiento	8,3	8,5	9,4	9,8	10,4	10,4	9,9	9,6	13,0	11,9	*10,1*
% sobre salida de embalse total	*0,81*	*0,94*	*1,03*	*1,04*	*1,84*	*1,39*	*1,13*	*1,38*	*1,37*	*1,40*	*1,2*
Hm³ de demanda en destino para industria	4,6	5,0	4,6	4,9	5,6	6,3	6,4	5,4	4,6	5,0	*5,2*
% sobre salida de embalse total	*0,45*	*0,55*	*0,50*	*0,51*	*0,99*	*0,84*	*0,73*	*0,78*	*0,49*	*0,59*	*0,6*
Hm³ de demanda en parcela para riego	848,6	764,4	783,8	821,1	455,2	635,0	758,0	600,8	681,7	759,0	*710,8*
% sobre salida de embalse	*82,77*	*84,09*	*85,93*	*86,52*	*80,46*	*84,92*	*86,65*	*86,29*	*71,82*	*89,54*	*83,90*
Hm³ de demanda en parcela o destino para riego, industria y abastecimiento	861,5	778,0	797,8	835,8	471,2	651,7	774,2	615,8	698,7	775,9	*726,1*
% Eficiencia en el transporte	*84,03*	*85,57*	*87,46*	*88,07*	*83,29*	*87,16*	*88,51*	*88,44*	*73,68*	*91,53*	*85,77*
Hm³ de pérdida del transporte de embalse a destino	163,7	131,2	114,4	113,3	94,5	96,0	100,5	80,5	253,3	71,8	*121,9*
% Pérdida de transporte	*15,97*	*14,43*	*12,54*	*11,93*	*16,71*	*12,84*	*11,49*	*11,56*	*26,32*	*8,47*	*14,23*
Demanda media servida en salida de embalse para riego (m³/ha pleno derecho)	8.732	7.703	7.700	7.787	4.528	6.092	7.078	5.602	7.695	6.815	*6.973*

Fuente: Elaboración propia con datos de la CGRAA.

Por tanto, como primer resultado observamos que la tendencia seguida en el siglo XX de incremento de la oferta de agua suministrada no se corresponde con los hechos observados en la primera década del siglo XXI en la CGRAA, véanse los trabajos previos de Faci *et al*. (2000 [71]) y de Playán *et al*. (2000 [145]) que concluyeron que el sistema de distribución actual del agua en el regadío en la zona de la CGRAA no era capaz de suministrar una oferta de agua flexible y garantizada a los agricultores. Estos autores señalan que los sistemas de riego fueron construidos para el riego de cultivos de invierno, por lo que el aumento a finales del siglo pasado de cultivos más intensivos y que se riegan fundamentalmente en primavera y verano incrementó las necesidades reduciendo la capacidad del sistema para cubrirlas y la garantía de suministro.

Por otro lado, la superficie de riego muestra una tendencia creciente. En concreto, podemos destacar que desde el año 2001, se ha incrementado la superficie regada en más de 5.963 hectáreas de pleno derecho. Pero el gran aumento en el número de hectáreas se produce a finales del siglo anterior, ya que en 1994 el número de hectáreas rondaba las 96.666 hectáreas (véase Sánchez-Chóliz y Duarte, 2006 [161]). En los últimos quince años ha aumentado la extensión del regadío de la CGRAA en aproximadamente 30.000 hectáreas, mientras un volumen de agua cada vez menor es usado para regar una superficie que ya supera en estos momentos las 130.000 hectáreas y que continúa en expansión. Esto ha hecho que la dotación media en salida de embalse para riego haya sido en media de sólo 6.973 m^3/ha al año, aunque para 2005 y 2008 fue mucho menor (4.528 m^3/ha y 5.602 m^3/ha respectivamente).

En la Tabla 1.2 vemos también que la demanda de agua, ya sea para uso industrial, abastecimiento o riego ha sido en promedio de 726,1 hm^3, lo que supone una eficiencia en el transporte desde el embalse del 85,77% en promedio y una pérdida media del 14,23%. Notemos que con la excepción del año 2009, hay una clara tendencia creciente en la eficiencia del proceso de transporte, que pasa del 84,03% en 2001 al 91,53% en 2010. Cabe destacar que las pérdidas de agua que se producen en el año 2009 son debidas a que los volúmenes de agua suministrados desde el embalse son superiores a los necesarios, debido en parte a las importantes precipitaciones invernales de ese año y a los excesos existentes en las reservas de agua del embalse que obligaron a realizar importantes vertidos.

Como conclusión, podemos asegurar que la tendencia decreciente de los suministros de agua de riego en la CGRAA no se corresponde con la tendencia al aumento de la oferta de agua observada en las últimas décadas del siglo XX, aunque por otro lado, sí que se mantiene como en ese siglo un permanente crecimiento de la superficie de regadío. Esto sólo ha sido posible por el importante avance dado en la modernización, que ha supuesto cambios muy importantes en los cultivos, en los costes y en las estructuras empresariales. Estos hechos son la base para nuestra conjetura de que el agua servida para regar las hectáreas de la CGRAA se utiliza cada vez con más eficiencia.

1.2.3. Necesidades hídricas y eficiencia en el uso del agua

Para estimar los niveles de eficiencia en el uso de agua para riego, es preciso conocer primero las necesidades hídricas netas de cada uno de los cultivos según la zona donde se encuentren, entendidas éstas como el volumen de agua por hectárea que necesita cada cultivo para su supervivencia, es decir, el agua adicional que necesita la planta durante su ciclo de vida por encima de la precipitación media mensual correspondiente. Las comarcas sobre las que se extienden las 58 comunidades que agrupan la CGRAA son Monegros, Hoya de Huesca, Somontano de Barbastro, Zaragoza, Bajo Cinca y Cinca Medio. Como la información disponible sobre necesidades hídricas de los cultivos es de tipo comarcal (véase Martínez-Cob *et al.*, 1998 [128]), la relación geográfica entre las comunidades de regantes y comarcas permite aproximarse a las necesidades hídricas de cada cultivo en cada comunidad de riego, y por consiguiente, al volumen de agua requerido en cada comunidad. Los resultados obtenidos, basados en datos mensuales medios y que suponen unas condiciones climáticas medias, pueden verse en la Tabla 1.3.

Tabla 1.3. **Necesidades hídricas netas en m³/ha**

Cultivos	Monegros	Hoya de Huesca	Zaragoza	Somontano de Barbastro	Bajo Cinca	Cinca Medio	Media ponderada[7]
Trigo	2.420	1.890	2.480	2.140	2.610	2.375	*2.309*
Cebada	2.050	1.570	2.090	1.520	2.230	1.943	*1.900*
Maíz	5.520	4.940	5.900	5.040	5.760	5.405	*5.372*
Arroz	8.450	7.840	8.145	8.145	8.145	8.145	*8.282*
Avena	4.678	4.102	4.713	4.207	4.825	4.825	*4.542*
Otros cereales	4.950	4.270	4.950	4.190	5.380	3.438	*4.643*
Cultivos industriales	4.850	4.370	5.000	4.260	5.060	4.647	*4.686*
Leguminosas	1.335	1.335	1.335	1.335	1.335	1.335	*1.335*
Patata	4.455	4.455	4.455	2.935	2.935	2.935	*4.045*
Alfalfa en verde	6.610	5.440	7.010	5.530	7.190	6.310	*6.286*
Otras plantas forrajeras	3.880	3.295	4.235	3.340	4.170	3.730	*3.721*
Hortalizas	3.717	3.717	3.717	3.542	3.542	3.542	*3.670*
Frutales	6.287	5.489	7.023	5.489	7.085	6.287	*6.093*
Almendro	5.300	5.300	5.300	5.300	5.300	5.300	*5.300*
Olivo	2.880	2.880	2.880	2.880	2.880	2.880	*2.880*
Viñedo	4.730	4.730	4.660	4.730	4.730	4.730	*4.729*

Nota: Se consideran como pérdidas de riego y por tanto no incluidas en las necesidades hídricas, la totalidad de la escorrentía y la percolación, la evaporación del terreno y las pérdidas por el viento. Si parte de esas cantidades de agua no se consideraran pérdidas, en particular la percolación profunda o la evaporación del terreno, los niveles de eficiencia que se estimarían serían mayores.

Fuente: Elaboración propia a partir de Martínez-Cob *et al*. (1998 [128]).

El cultivo del maíz, arroz, alfalfa y frutales son los que mayor volumen de agua requieren, mientras que otros cultivos como trigo, cebada o leguminosas son los que menos.

1.2.3.1. Niveles de eficiencia

En los sistemas de riegos se producen pérdidas tanto en el transporte hasta el campo como en los procesos de cultivo, por ello vamos a definir y analizar tres tipos de eficiencia: la eficiencia en baja, la eficiencia total y la eficiencia en alta o del transporte. En las siguientes ecuaciones se define cada una de ellas:

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[7] Se pondera en función de la participación de cada comarca en la superficie de regadío de la CGRAA en el año 2010.

$$Eficiencia\ en\ baja^{8} = \frac{necesidades\ hídricas\ netas\ de\ los\ cultivos}{agua\ que\ se\ aplica\ a\ las\ parcelas} \qquad \text{Eq. (1.1)}$$

$$Eficiencia\ en\ alta = \frac{agua\ que\ se\ aplica\ a\ las\ parcelas}{agua\ tomada\ del\ embalse\ principal} \qquad \text{Eq. (1.2)}$$

De modo que:

$$Eficiencia\ total = eficiencia\ en\ baja \times eficiencia\ en\ alta \qquad \text{Eq. (1.3)}$$

Como ya hemos visto en la Tabla 1.2, el nivel medio de eficiencia en alta[9] a lo largo de la década se sitúa en torno al 85,77%, un porcentaje elevado que, salvo en el año 2009, muestra una tendencia creciente. Una estimación exacta del resto de eficiencias de la CGRAA requiere la disponibilidad de los datos de usos y demandas de cada una de sus 58 comunidades. En este trabajo, sólo se han tenido en cuenta 45 comunidades a lo largo de los diez últimos años, pero estas comunidades representan el 98% del total de superficie de regadío de la CGRAA, por lo que las estimaciones obtenidas son robustas y pueden considerarse muy representativas de la situación real de la CGRAA.

Para estimar las anteriores eficiencias, en primer lugar, se realiza un análisis de la distribución de la superficie de riego por tipo de cultivos en cada una de las comunidades, partiendo de las distribuciones de cultivos de regadío por municipios obtenida de DGA (2011a [57]). En segundo lugar, una vez obtenido el número de hectáreas de cada cultivo, multiplicando por las necesidades hídricas netas de cada cultivo expuestas en la Tabla 1.3 se obtuvo para cada comunidad el volumen de agua requerida por los cultivos, dada la precipitación media estimada en cada zona y sin

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[8] El concepto de eficiencia en baja utilizado, que no es el usual, es una medida conjunta del déficit hídrico de la planta y de la eficiencia de las tecnologías de riego. En este sentido se podría descomponer en el producto de la ratio entre necesidades hídricas de los cultivos y el agua aplicada realmente al cultivo, una medida del déficit hídrico de la planta, y el cociente del agua aplicada realmente al cultivo en la parcela dividida por el agua que llega a ésta, que mide la eficiencia del sistema de riego. A pesar de ello, por simplicidad no se ha descompuesto el concepto de eficiencia en baja al no condicionar el objetivo final del trabajo y no afectar a las estimaciones buscadas de déficit ni a las conclusiones obtenidas.

[9] Debido a la dificultad de su estimación, no se dispone del volumen de agua tomado del embalse de forma individualizada para cada parcela, lo que no permite diferenciar la eficiencia en alta de unas comunidades a otras y el dato disponible en la Tabla 1.2 es el valor medio para toda la CGRAA.

contabilizar en las necesidades el agua de escorrentía, la percolación profunda ni otras pérdidas.

En la Tabla 1.4 se resumen los niveles de eficiencia en baja y total alcanzados. Los datos por comunidades pueden verse en el Anexo.[10] La eficiencia total promedio en los últimos diez años en las comunidades analizadas de la CGRAA ha sido del 61% si suponemos que el agua se dedica únicamente a las hectáreas de pleno derecho.[11] Si se supone que se riegan el total de hectáreas que agrupan la CGRAA, el nivel de eficiencia alcanza el 62%. Teniendo en cuenta que la pérdida media del transporte de agua desde el embalse a parcela es del 14,23%, la eficiencia en baja media en la CGRAA a lo largo de la década es del 72% si se considera que se riegan las hectáreas de pleno derecho, y del 73% si se riegan todas las hectáreas. Estos niveles suponen un uso bastante eficiente, aunque mejorable, del agua para riego, especialmente si tenemos en cuenta dos cosas; la primera que incluyen como pérdidas la percolación profunda, el arrastre del viento y la evaporación en la aplicación, que en Huesca pueden alcanzar el 9,5% (MARM, 2001 [125]); y segunda, que en la CGRAA el peso de los cultivos leñosos no es elevado, representan menos del 3% de la superficie total, y que no es previsible a corto plazo un cambio radical a favor de los cultivos leñosos en la estructura de cultivos. Para situar históricamente la transformación que esto supone, conviene recordar que los niveles de eficiencia total hace tres o cuatro décadas estaban situados alrededor del 45%.

Tabla 1.4. **Niveles de eficiencia en baja y total (2001-2010)**

	Has pleno derecho	Has totales
Eficiencia en baja	72%	73%
Eficiencia total	61%	62%

Fuente: Elaboración propia con datos de la CGRAA.

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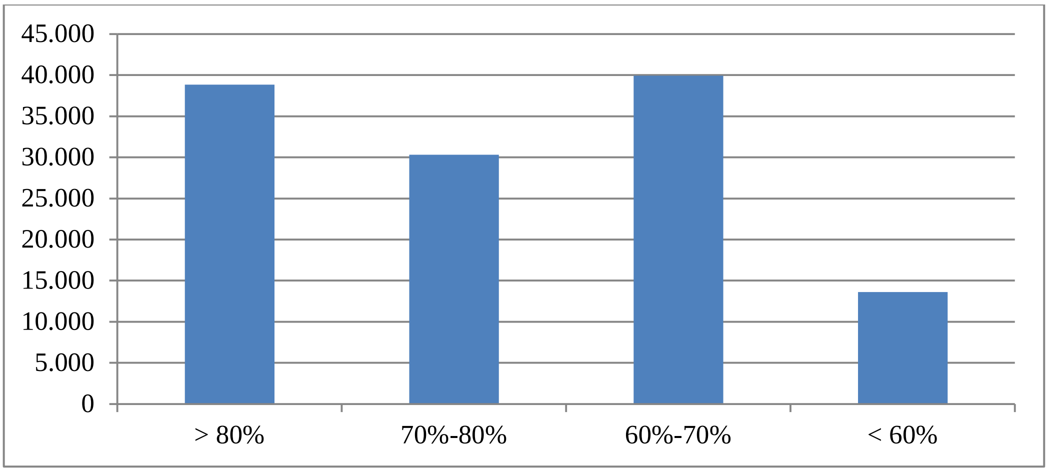
[10] En la tabla del Anexo por comunidades aparecen valores de eficiencia en baja y total del 100%, especialmente en la columna correspondiente al año 2005. Estas cifras corresponden a riegos en precario, que usan cantidades de agua por debajo de las que necesita la planta y que llevan a cifras de eficiencia, de acuerdo con la definición establecida, superiores al 100%. En todas las estimaciones que usamos en el trabajo, las eficiencias usadas nunca superan el 100%, y coinciden con las de la tabla del Anexo, corrigiendo parcialmente el sesgo que producen los riegos en precario.

[11] Hace dos décadas, la Food and Agriculture Organization of United Nations (FAO) consideró que niveles de eficiencia total entre el 50 y 60% podían ser valorados como “good efficiency” (véase FAO, 1989 [72]; Annex I).

Estos resultados coinciden con trabajos previos que estiman el nivel de eficiencia en el Alto Aragón. Tedeschi *et al*. (2001 [177]) estiman niveles de eficiencia del 60% a finales del siglo XX en la zona de Monegros II. Playán *et al*. (2000 [145]) calculan niveles medios de eficiencia del 62% a principios del siglo XXI, obteniendo mejores resultados en algunas zonas con niveles de eficiencia en baja del 77%. En trabajos más recientes, García *et al*. (2009 [79]) estiman niveles de eficiencia de riego medios del 73% en la Comunidad de Regantes nº V del Canal de Bárdenas próxima a la CGRAA. Este trabajo, por tanto, confirma estos resultados parciales, rellenando las lagunas existentes y dando estimaciones de los niveles de eficiencia de riego y de los usos para el conjunto de la CGRAA y para cada una de las comunidades que la componen.

La Figura 1.2 clasifica la superficie de regadío de acuerdo con el nivel de eficiencia en baja obtenido. Casi una tercera parte del regadío de la CGRAA tiene una eficiencia en baja superior al 80%. Otro 25% de la superficie la tiene entre el 70% y 80%, lo que hace que más del 50% de la superficie total de la CGRAA tenga un buen nivel de eficiencia en baja. No olvidemos que son regadíos abiertos, no en invernadero. Por el contrario, sólo un 11% de la superficie tiene niveles de eficiencia en baja inferiores al 60%. Sobre esta superficie y sobre un tercio más que tiene el nivel de eficiencia en baja entre el 60% y 70%, es donde debería centrarse la política de modernización. Estos resultados, y las mejoras observables respecto a la situación de hace unas décadas, sólo han sido posibles por los procesos de modernización recientes y en marcha (Tabla 1.1).

Figura 1.2. **Hectáreas de pleno derecho según nivel de eficiencia en baja**



Fuente: Elaboración propia con datos de la CGRAA.

1.2.3.2. Evolución de los niveles de eficiencia

En la Tabla 1.5 se observa la evolución anual a lo largo de la década de los tres niveles de eficiencia: en alta, en baja y total, revelándose una tendencia ligeramente creciente en los tres niveles. Esto se debe en buena medida a la mejora en las técnicas de riego empleadas, mejoras que han sido forzadas por la lenta reducción de los volúmenes de agua disponibles y por el incremento de superficie regada. En el año 2005, el año más seco de la década en esta zona, se observa un aumento del déficit hídrico lo que genera niveles de eficiencia tanto en baja como total muy elevados que alcanzan el 80% y 96% respectivamente, resultados similares a los obtenidos para ese año en García *et al*. (2009 [79]), aunque la eficiencia en alta disminuye. También en 2008, otro año seco, aumentan significativamente los niveles de eficiencia en baja y total, pero esta vez la eficiencia en alta mantiene un nivel de eficiencia elevado. En el año 2009 se observa una importante caída en la eficiencia total, pero esta no se produce por un uso ineficiente del agua en baja, ya que esta mantiene un nivel elevado, sino por un aumento en la disponibilidad de agua, que obliga a realizar vertidos por falta de volumen de almacenamiento y que hace caer la estimación de la eficiencia en alta.

Tabla 1.5. **Evolución anual de los tres niveles de eficiencia**

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	*Promedio*
En alta	84%	86%	87%	88%	83%	87%	89%	88%	74%	92%	*86%*
En baja	66%	68%	69%	66%	96%	78%	65%	71%	71%	65%	*72%*
Total	55%	58%	60%	58%	80%	68%	58%	63%	52%	59%	*61%*

Fuente: Elaboración propia con datos de la CGRAA.

1.2.3.3. ¿Es suficiente el agua disponible para el riego de los cultivos?

Una vez que se conocen los niveles de eficiencia y las necesidades hídricas de cada planta, es posible comprobar si el volumen de agua suministrado a la CGRAA y que ha mostrado una tendencia ligeramente decreciente, es suficiente para el riego de los cultivos, o si por el contrario existe un déficit para cubrir sus necesidades hídricas. En la Tabla 1.2 se obtenía una dotación en salida de embalse de 6.973 m^3/ha como promedio de los diez años. Como el nivel de eficiencia total es del 61%, con esos 6.973

m^3/ha se tiene una dotación neta media de 4.254 m^3/ha. Si nos fijamos en la Tabla 1.3, los 4.254 m^3/ha son insuficientes en todas las comarcas de la comunidad para el riego de cultivos como el maíz, el arroz, los cultivos industriales, la patata, la alfalfa, los frutales, el almendro o el viñedo. Si la eficiencia total se elevara al 70%, con esos 6.973 m^3/ha se obtendría una dotación de 4.881 m^3/ha, que sigue siendo insuficiente para el maíz, el arroz, la alfalfa, los frutales o el almendro en todas las comarcas. En consecuencia, incluso en un año medio es imposible dedicar la totalidad de la superficie a cultivar maíz, arroz, alfalfa, frutales o almendro, que son los productos más rentables y de gran interés por su papel básico para la industria, la elaboración de piensos y la importación. El cultivo de estos productos sólo es posible si se combina con otros productos menos exigentes de agua, como trigo, cebada, leguminosas, olivo,…, aunque sean menos rentables (Tedeschi *et al*., 2001 [177]). Por tanto, la introducción de productos más exigentes de agua en la CGRAA, que tengan una mayor rentabilidad económica y que permitan hacer frente a la costosa modernización, puede verse realmente limitada por la falta e inseguridad del suministro de agua, con independencia de que estos cultivos sean económicamente viables y demandados por el mercado nacional e internacional.

Los resultados muestran por un lado que la dotación de agua es insuficiente en la situación actual del regadío, y por otro la reciente mejora de la eficiencia en el uso del agua mediante la modernización de los regadíos. Sin duda esta última opción es importante pero tiene claros límites, ya que algunas pérdidas en el uso del agua resultan inevitables o muy difíciles de reducir, como por ejemplo las pérdidas por percolación profunda. Si como ya hemos visto, las pérdidas por el transporte están alrededor del 15% y las debidas a la percolación profunda, arrastre del viento y evaporación en la aplicación pueden alcanzar el 9,5% (MARM, 2001 [125]), será muy difícil lograr niveles de eficiencia en baja superiores al 85% y de eficiencia total superiores al 70%.

Por otra parte, aún finalizando la modernización y suponiendo que todos los regadíos con un nivel de eficiencia en baja actualmente inferior al 70% alcanzaran ese nivel de eficiencia, el ahorro de agua sin cambiar cultivos sería únicamente según nuestros datos de unos 90 hm^3, cifra inferior a los déficits que están teniendo lugar como veremos después. Además no debemos olvidar que la modernización en general no libera realmente agua, ya que los ahorros son absorbidos por la intensificación de los cultivos y por los cambios de estos. Recordemos finalmente algunas características particulares de la CGRAA como los largos periodos de riego, parcelas de tamaño pequeño o la dificultad para gestionar el riego nocturno durante el verano, que dificultan también la mejora de los niveles de eficiencia (Lecina *et al.*, 2010a [104]).

Para ser más concretos, vamos a intentar cuantificar cuál es la falta de agua o déficit bajo las condiciones actuales y vamos a hacerlo bajo dos supuestos, en el primero la estructura de cultivos será la de 2001, usándose en el segundo la estructura de cultivos media de 2001 a 2010. La primera corresponde al año más exigente en agua por hectárea cultivada de los años analizados, debido principalmente al mayor peso de la alfalfa y el maíz. Podemos considerarla una primera aproximación de la estructura hacia la que se tendería si no hubiera restricciones en la disponibilidad de agua. Los resultados se muestran en la Tabla 1.6. La segunda describe mejor la situación del año a año, y está claramente afectada por los procesos de ajuste que han realizado los agricultores con la información disponible al comienzo de campaña, los resultados se muestran en la Tabla 1.7. Pero en este caso, no debería olvidarse que la distribución media de cultivos que estamos usando está lejos de ser óptima, como veremos más tarde.

En ambas tablas puede verse la comparación entre el volumen de agua necesario para cubrir los requerimientos hídricos necesarios para el riego[12] con niveles de eficiencia total del 60% y 70% (la demanda requerida en ambas tablas), y el volumen de agua realmente suministrado a la CGRAA durante esos años. La diferencia entre estos volúmenes permite conocer el déficit y la disponibilidad de agua respecto a los volúmenes suministrados. Los valores positivos indican que el volumen de agua demandada superó al suministro, presentándose por tanto un déficit, por el contrario los valores negativos señalan que el volumen de agua suministrado cubrió totalmente las demandas. Nótese, que al elevarse el nivel de eficiencia, los déficits que se presentan son menores o pasan a superávits (cifras negativas), aumentando por el contrario los superávits (cifras negativas de mayor tamaño).

La Tabla 1.6 muestra que con un nivel de eficiencia total del 60%, muy similar al nivel actual, el volumen de agua suministrado desde los embalses habría sido insuficiente para cubrir la demanda requerida en todos los años salvo en 2001, porque en ese año el volumen de agua suministrado desde el embalse fue elevado y superó en 49 hm^3 las demandas requeridas. En concreto, en el año 2005, hubiesen faltado 430,6 hm^3. Si el nivel de eficiencia total lo elevamos al 70%, los volúmenes de agua

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[12] Se considera la media ponderada de los requerimientos hídricos obtenida en la Tabla 1.3.

suministrados hubieran sido suficientes para algunos años (2001, 2002, 2003, 2004 y 2009), pero en otros cinco años (2005, 2006, 2007, 2008 y 2010) no permiten cubrir las necesidades de los cultivos. Es importante notar que son los últimos años los que tienen déficits o falta de agua (salvo el 2009), habiendo influido en ello la menor disponibilidad de agua pero sobre todo el crecimiento constante de la superficie de regadío. Estos resultados revelan también la baja seguridad del suministro, que de cara a la rentabilidad es casi tan importante como el propio suministro.

Tabla 1.6. **Requerimientos de agua en la CGRAA para los cultivos del 2001**

		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
	Necesidades hídricas	586	590	592	594	598	599	614	603	605	606
	Hm^3 suministrados	1.025	909	912	949	566	748	875	696	949	848
Nivel de eficiencia 60%	Demanda requerida	976	984	986	990	996	998	1.023	1.004	1.009	1.009
	Hm^3 de déficit	-48,7	74,7	74,3	41,3	430,6	250,5	148,8	307,9	59,6	161,9
Nivel de eficiencia 70%	Demanda requerida	837	843	846	849	854	856	877	861	865	865
	Hm^3 de déficit	-188,2	-65,9	-66,6	-100,2	288,2	107,9	2,6	164,5	-84,5	17,7

Fuente: Elaboración propia con datos de la CGRAA.

Si estos cálculos se analizan para la distribución media de los cultivos entre 2001-2010, con un 60% de eficiencia se obtienen déficits de agua en cinco de los 10 años, aunque menores que antes porque la composición de los cultivos es menos exigente en agua.[13] Si el nivel de eficiencia total se eleva al 70%, sólo falta agua en tres años, los tres años más secos, habiendo sido el déficit obtenido para 2005 de más de 185 hm^3. No obstante, no debemos olvidar las condiciones para que esto ocurra, tener una eficiencia total del 70% y tener una estructura de cultivos muy alejada de lo deseable por rentabilidad.

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[13] No hay que olvidar que los propios agricultores, con la información disponible al principio de campaña, adaptaron sus cultivos a las disponibilidades de agua, lo que se refleja en la composición media de los cultivos y en una menor demanda de agua.

Tabla 1.7. **Requerimientos de agua en la CGRAA para la distribución media de cultivos 2001-2010**

		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
	Necesidades hídricas	515	519	521	523	526	527	540	530	532	533
	Hm³ suministrados	1.025	909	912	949	566	748	875	696	949	848
Nivel de eficiencia 60%	Demanda requerida	859	865	868	871	876	878	900	883	887	888
	Hm³ de déficit	-166,5	-43,9	-44,6	-78,1	310,4	130,2	25,4	186,8	-62,0	40,2
Nivel de eficiencia 70%	Demanda requerida	736	742	744	747	751	752	772	757	760	761
	Hm³ de déficit	-289,1	-167,5	-168,5	-202,5	185,3	4,8	-103,2	60,7	-188,7	-86,7

Fuente: Elaboración propia con datos de la CGRAA.

Por último, ante los planes previstos de extender la superficie de cultivo hasta 185.000 hectáreas, conviene preguntarnos si los niveles de suministro de agua actuales permitirán cubrir las necesidades hídricas de esos cultivos. Vistos los resultados anteriores la respuesta esperada es no, pero veámoslo con más detalle. En la Tabla 1.8 se plantean dos escenarios posibles, en el primer escenario se extiende la superficie de cultivo hasta las 150.000 hectáreas, y en el segundo escenario se alcanzan las 185.00 hectáreas, asumiéndose en ambos el patrón de cultivos del año 2001 y que el agua suministrada es la media de los diez años, 848 hm^3 (Tabla 1.2). Los resultados muestran que el déficit de agua alcanza los 620 hm³ si se quieren regar las 185.000 hectáreas con un nivel de eficiencia total del 60% y los 410 hm³ si el nivel de eficiencia total se eleva al 70%. Las cifras son menores para las 150.000 has, pero son también elevadas, 342 hm^3 y 172 hm^3.

Tabla 1.8. **Previsiones de requerimientos de agua (Hm³)**

Hectáreas	150.000		185.000	
Nivel de eficiencia total	60%	70%	60%	70%
Necesidades hídricas	714	714	881	881
Hm³ demanda requerida	1.190	1.020	1.468	1.258
Hm³ suministrados	848	848	848	848
Hm³ de déficit	342	172	620	410

Fuente: Elaboración propia con datos de la CGRAA.

Es frecuente replicar la anterior argumentación diciendo que la solución son las regulaciones pendientes, pero esto cambia poco el problema como veremos con más detalle en las conclusiones. Las dos principales regulaciones pendientes en la CGRAA son el pantano de Biscarrués y la Balsa reguladora de Almudévar, que tendrán capacidades de 35 hm^3 y 169 hm^3, claramente insuficientes para cubrir el déficit y asegurar el regadío de las 185.000 hectáreas según la Tabla 1.8. Podrían sin duda paliar una buena parte de los déficits en el caso de las 150.000 hectáreas si con la modernización se alcanza una eficiencia del 70%. Sin embargo, no debemos olvidar que estamos hablando de valores medios, lo que significa que tampoco serían suficientes para las 150.000 hectáreas si el año es seco.

1.2.4. Evolución del patrón de cultivos

En el apartado anterior hemos utilizado la distribución de la superficie de riego por cultivos para conocer el volumen de agua requerido por los cultivos en la CGRAA. En este apartado vamos a analizar si se ha producido o no un cambio en los patrones de los cultivos en los últimos años como consecuencia de las dotaciones de agua, observando sobre todo la evolución de la superficie cultivada, la producción de cada cultivo y su rentabilidad.

1.2.4.1. Evolución anual por grupos de cultivos

El patrón de cultivos depende de varios aspectos fundamentales, entre los que destaca la disponibilidad de recursos hídricos, los costes de producción y las subvenciones, en concreto las ayudas procedentes de la Política Agraria Común (PAC en adelante). La mayor regulación de la oferta de recursos hídricos a lo largo del siglo XX permitió a los agricultores introducir cultivos con mayores requerimientos hídricos (Pinilla, 2006 [143]). En la CGRAA, durante los años ochenta, se redujeron cultivos como los cereales de invierno para introducir cultivos como el maíz, el arroz o los forrajes (Silvestre y Clar, 2010 [172]). En concreto, en regadíos próximos a la CGRAA durante los años noventa el cultivo de la alfalfa pasó de ocupar el 4% de la superficie al 43,4% (Dechmi *et al.*, 2003 [49]).

La Tabla 1.9 muestra la evolución anual de la superficie de riego de los principales cultivos, en la que puede verse el profundo cambio que ha tenido lugar en la distribución de las superficies de cultivo desde el año 2001 al año 2010.

Tabla 1.9. **Evolución de la superficie de los principales cultivos en la CGRAA (Has)**

Cultivos	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Trigo	2.489	5.053	4.342	5.719	4.157	5.319	7.346	9.475	5.517	8.162
%	*2,21*	*4,48*	*3,85*	*5,07*	*3,64*	*4,60*	*6,28*	*8,08*	*4,72*	*6,86*
Cebada	9.992	12.665	12.469	13.430	14.668	18.825	20.676	31.683	23.175	26.662
%	*8,89*	*11,24*	*11,06*	*11,91*	*12,85*	*16,27*	*17,69*	*27,03*	*19,81*	*22,40*
Maíz	40.712	34.978	37.001	35.417	22.688	24.258	26.723	22.361	26.412	23.494
%	*36,21*	*31,03*	*32,81*	*31,40*	*19,88*	*20,97*	*22,86*	*19,08*	*22,58*	*19,74*
Alfalfa	29.253	30.527	31.208	31.459	29.478	30.003	25.838	22.031	26.510	27.921
%	*26,02*	*27,08*	*27,67*	*27,89*	*25,83*	*25,94*	*22,10*	*18,79*	*22,66*	*23,46*
Arroz	5.487	5.162	5.245	6.282	4.542	4.631	6.345	4.445	5.717	6.693
%	*4,88*	*4,58*	*4,65*	*5,57*	*3,98*	*4,00*	*5,43*	*3,79*	*4,89*	*5,62*
Cultivos industriales	9.069	4.349	4.975	3.610	2.271	1.712	1.099	1.759	1.707	864
%	*8,07*	*3,86*	*4,41*	*3,20*	*1,99*	*1,48*	*0,94*	*1,50*	*1,46*	*0,73*

Fuente: Elaboración propia a partir de los datos de la DGA (2011a [57]).

Como se observa, la alfalfa se ha mantenido a lo largo del período, aunque muestra una ligera tendencia decreciente. La superficie destinada al cultivo del trigo ha crecido más del triple, a diferencia de la tendencia observada a finales del siglo anterior. La superficie destinada a la cebada se ha incrementado casi al triple, produciéndose el gran cambio principalmente en los años 2002, 2005 y 2008, lo que indica que esta evolución estuvo muy ligada al volumen de agua suministrada, que cae en los tres años (Tabla 1.2). No debemos olvidar que el cultivo de la cebada proporciona gran flexibilidad a los agricultores al poderla cultivar en los años más secos porque es menos exigente en agua y existir variedades de cebada de ciclo corto que se siembran en invierno. Respecto al maíz, su superficie se reduce de un 36,21% de la superficie total en 2001 a un 19,7% en 2010. El cultivo del girasol prácticamente ha desaparecido, su expansión en los años noventa se debió principalmente a las subvenciones a este cultivo por parte de la Comunidad Europea (Faci *et al*., 2000 [71]). La superficie destinada al cultivo del arroz es prácticamente fija debido a que buena parte de los terrenos dedicados al arroz son tierras con condiciones de salinidad que no favorecen a otros cultivos, y también a las ayudas específicas recibidas para este cultivo por parte de la PAC (Atance *et al*., 2006 [10]).

Resumiendo, en la década 2001-2010 se ha producido un cambio significativo en los patrones de cultivo hacia el cultivo de cebada y trigo, cultivos que consumen menor cantidad de agua, todo ello muy influenciado como vamos a ver por las deficiencias en el agua disponible para riego y por el cambio experimentado en las ayudas procedentes de la PAC. A partir de 2006 las ayudas fueron en gran parte desacopladas (Atance *et al*., 2006 [10]).

1.2.4.2. Rentabilidad de los cultivos

Para confirmar la anterior afirmación vamos a analizar también la evolución de la producción (en toneladas) de los cultivos más significativos (ver Tabla 1.10). La producción de cebada en toneladas se ha triplicado al igual que ocurre con el trigo. La producción del maíz ha disminuido, produciéndose la caída especialmente en los años secos de 2005 y 2008, aunque muestra una ligera recuperación en los últimos años. Por su parte, la producción de la alfalfa cae ligeramente, un 12,5% aproximadamente de 2001 a 2010, con caídas mayores en 2005 y 2008, de nuevo los años secos, aunque su caída es inferior a la del maíz que llega al 23,74%, como también se señala en Barros *et al*. (2011 [20]) y en García *et al*. (2009 [79]). Por tanto, esta evolución es coherente con la reducción de las disponibilidades de agua, que se manifiestan especialmente en los años de sequía.

Tabla 1.10. **Evolución de la producción en la provincia de Huesca (Tn)**

Cultivos	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Trigo	25.287	58.786	52.710	40.186	33.317	63.917	73.223	87.987	58.786	78.755
% de 2001	*100,00*	*232,48*	*208,45*	*158,92*	*131,76*	*252,77*	*289,57*	*347,95*	*232,48*	*311,44*
Cebada	81.712	194.945	128.962	128.005	92.676	194.613	201.488	209.183	194.945	248.098
% de 2001	*100,00*	*238,58*	*157,83*	*156,65*	*113,42*	*238,17*	*246,58*	*256,00*	*238,58*	*303,62*
Maíz	565.176	413.711	457.476	551.598	308.848	312.334	394.930	286.243	413.711	431.016
% de 2001	*100,00*	*73,20*	*80,94*	*97,60*	*54,65*	*55,26*	*69,88*	*50,65*	*73,20*	*76,26*
Alfalfa	3.493.542	2.887.924	2.991.207	3.078.500	2.427.515	3.349.808	3.036.080	2.703.786	2.887.924	3.058.924
% de 2001	*100,00*	*82,66*	*85,62*	*88,12*	*69,49*	*95,89*	*86,91*	*77,39*	*82,66*	*87,56*

Fuente: Elaboración propia a partir de DGA (2011b [58]).

¿Ha influido en la evolución posibles cambios en los rendimientos por hectárea? La comparación de las cifras de las Tablas 1.9 y 1.10 excluye esta posibilidad, ya que el valor del ratio: toneladas/hectárea, obtenido a partir de ambas tablas es a lo largo de la década muy similar en trigo y cebada, mejora muy ligeramente en alfalfa y mejora notablemente en maíz. No explica por tanto la evolución que hemos vistos en los patrones de cultivo, incrementos de rendimientos del trigo y cebada, y caídas en maíz y alfalfa. Más aún, si comparamos el rendimiento de los principales cultivos en la provincia de Huesca respecto a la media española (ver Tabla 1.11), observamos que las características del suelo de Huesca favorecen los cultivos del maíz y de la alfalfa en el regadío, cuyas producciones han caído a lo largo de la década, teniendo el primero un rendimiento medio similar al de España pero elevado, y el segundo un rendimiento muy superior a la media española. Mientras que otros cultivos como el trigo, la cebada, cuyas producciones han crecido, y el arroz tienen un menor rendimiento en Huesca que en el resto de España.

Tabla 1.11. **Rendimiento de cultivos de regadío (kg/ha). Promedio 2001-2008**[14]

Cultivos	Huesca	España
Trigo	4.097	4.375
Cebada	4.032	4.190
Maíz	9.993	10.106
Arroz	5.535	7.098
Girasol	2.147	1.923
Alfalfa	72.415	59.891

Fuente: Elaboración propia a partir de MARM (2001-08 [123]) y DGA (2011b [58]).

Si volvemos la vista a la estricta rentabilidad económica de los cultivos obtenemos la misma conclusión, la evolución de los cultivos ha dependido sobre todo de la disponibilidad de agua y en menor medida de la rentabilidad. La Tabla 1.12 muestra el margen bruto de los principales cultivos en Aragón. Estas cifras permiten observar los resultados económicos (ventas + subvenciones – costes directos) y son una de las herramientas básicas para la toma de decisiones de los agricultores. Los cultivos más rentables por hectárea son la alfalfa y el maíz, y sin embargo sus producciones han caído sistemáticamente a lo largo de la década. También vemos que el trigo y la cebada han ido perdiendo rentabilidad, y sin embargo sus producciones han crecido.

En el caso del maíz podemos ver en la Tabla 1.12 que su rentabilidad cayó muchísimo en 2008 y que tuvo una ligera recuperación en el año 2009, habiéndose mantenido a pesar de todo en 2008 por encima de la rentabilidad de la cebada y superando en 2009 tanto al trigo como a la cebada. Esta caída de rentabilidad no puede atribuirse de forma principal a la sequía, que no existió en 2009, se debió principalmente a la caída de precios y a los aumentos de costes tras la subida del precio de los abonos, y ello a pesar de que el rendimiento del cultivo del maíz (kg/ha) se mantuvo. Esto debe advertirnos de que no todo debe atribuirse de una forma simplista a la disponibilidad de agua, el mercado es muy importante y juega también un papel fundamental en la producción de regadío y en su comercialización.

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[14] Los datos de 2009 y 2010 no están disponibles.

Tabla 1.12. **Evolución del margen bruto estándar para cultivos de regadío (€/ha)**

Cultivos	2001	2002	2003	2004	2005	2006	2007	2008	2009
Trigo	597,13	737,59	622,09	699,35	601,63	438,16	737,49	549,47	477,49
Cebada	436,43	562,91	613,04	517,36	507,38	429,13	689,76	403,87	288,55
Maíz	955,94	1.116,45	1.127,31	1.173,17	1.014,35	1.108,05	1.581,82	500,08	724,19
Alfalfa	1.078,87	1.030,12	1.114,02	1.093,39	1.061,67	815,34	1.037,49	1.393,81	1.133,49

Fuente: MARM (2001-2009 [124]).

En definitiva, podemos afirmar que han sido la falta de agua en los años más secos, como el año 2005, y la caída de dotación por hectárea a lo largo de toda la década los motores principales que han llevado a reducir los cultivos más exigentes de agua, principalmente el maíz, y los que están llevando hacia cultivos menos exigentes como la cebada y el trigo, a pesar de que la rentabilidad económica de estos últimos cultivos es inferior e incluso se está reduciendo en los últimos años. En el año 2008, de nuevo con restricciones hídricas severas, esta tendencia se ha visto agravada por la menor rentabilidad económica del cultivo del maíz y por el cambio en la PAC hacia subvenciones no asociadas a la superficie cultivada, y por tanto, no dependientes de los cultivos concretos (desacoplamiento).

1.2.5. Conclusiones

En los últimos años ha tenido lugar un fuerte debate sobre la orientación de la planificación hidrológica en España. A lo largo del siglo XX, han predominado los modelos de oferta centrados en el fomento de infraestructuras que permitían cubrir las demandas crecientes de agua y la expansión de la superficie regada. Por el contrario, en la actualidad se trabaja con otros principios que buscan sobre todo la eficiencia, la sostenibilidad y el mantenimiento del buen estado de las aguas. En este marco, las comunidades de regantes pueden jugar un papel fundamental, ya que son los principales usuarios del agua regulada y obtienen sus rentas de los usos de ésta.

Es en este contexto donde se sitúa este trabajo, que analiza la situación hídrica del Alto Aragón durante la primera década del siglo XXI, en concreto realiza un estudio de las demandas de agua, los niveles de eficiencia en el uso de agua para riego y la estructura de los cultivos y su rentabilidad para la Comunidad General de Riegos del Alto Aragón, un sistema de regadío que concentra 2/3 aproximadamente del regadío de Huesca y que incluye 58 comunidades de regantes.

Desde el punto de vista de la demanda, esta Comunidad general se enfrenta a varios hechos, por una parte debe cubrir demandas crecientes por parte de los abastecimientos urbanos (ya que se extiende por una región de gran aridez) y de las industrias. Estas demandas presentan una menor elasticidad y una mayor rigidez que las demandas de los agricultores, aunque porcentualmente en estos momentos son una parte pequeña de los usos. Por otra, el agua regulada suministrada a la CGRAA por la CHE ha sido claramente decreciente a lo largo de la década. Y parece que esta caída puede ser permanente o incluso agravarse, ya que es debida con alta probabilidad a los procesos de revegetación en cabecera de los ríos y a los efectos del cambio climático. Esto representa un cambio muy importante respecto a la situación del siglo anterior, caracterizada por el incremento de la oferta y la disponibilidad creciente de agua. Más aún, la superficie regada en la CGRAA es cada año mayor y la tendencia marcada por los planes previstos es la de mantener este crecimiento. Todo ello lleva sin duda a la necesidad de replantear en profundidad la gestión hídrica por parte, tanto de la CHE, como de las propias comunidades de regantes.

Como el agua suministrada a la CGRAA no ha crecido en los últimos 20 años (su regulación es prácticamente la misma que hace dos décadas) pero sí lo ha hecho la superficie regada, los hechos nos obligan a asumir que en la actualidad se está utilizando el agua de forma más eficiente que a principios de siglo, sólo así se puede regar más superficie con las mismas dotaciones. Esta es una idea guía del trabajo.

Usando datos altamente fiables: informaciones de consumos reales por cada comunidad a lo largo de los 10 años, facilitados por la propia CGRAA; suministros de agua regulada hechos a la Comunidad general por la CHE; y por último, la información disponible sobre estructuras de cultivos anuales disponibles por el Gobierno de Aragón, ha sido posible obtener estimaciones muy robustas de los niveles de eficiencia y de los déficits potenciales de la CGRAA.

Del total de agua suministrada a la comunidad desde el embalse, una media del 85,77% es realmente utilizada en la comunidad. Esto refleja una baja pérdida de agua en el transporte a las parcelas, de sólo el 14,23% (es de tipo abierto, no por tuberías). Además estas pérdidas son todavía menores porcentualmente en los periodos de plena utilización de los canales de transporte, es decir, durante la campaña de riego.

Los resultados señalan una eficiencia total media en la CGRAA a lo largo de los diez años del 61%, que supone un nivel de eficiencia en baja media del 72%. Todo ello representa un salto impresionante respecto a la situación de hace tres o cuatro décadas, se ha pasado de eficiencias inferiores al 45% a una eficiencia de más del 60%, pero además hay en estos momentos un proceso de modernización acelerado en el que ¾ de la superficie ya se han modernizado, pasando del riego por gravedad a riego localizado o por aspersión.

Dado el nivel de eficiencia alcanzado del 61%, con la dotación media a lo largo de la década de 6.973 m^3/ha se ha tenido una dotación neta (eliminadas las pérdidas) para la planta de 4.254 m^3/ha, lo que resulta insuficiente para cultivos como el maíz, el arroz, los cultivos industriales, la patata, la alfalfa, los frutales, el almendro o el viñedo. Si la eficiencia total se elevara al 70%, la dotación que se obtendría seguiría siendo insuficiente para el maíz, el arroz, la alfalfa, los frutales o el almendro. Esta insuficiencia se hará más grave a medida que la extensión de cultivo en regadío crezca como está previsto. En concreto, si se pasa a las 185.000 hectáreas previstas, los déficits obtenidos de 620 y 410 hm^3 según el nivel de eficiencia serían tan elevados que será imposible cubrirlos con garantía con las dotaciones actuales. Y aunque sólo se llegase a las 150.000 hectáreas, las dotaciones actuales serían igualmente insuficientes ya que se obtendría un déficit de 172 hm^3, aún con niveles de eficiencia total del 70%.

En los últimos años, el maíz y la alfalfa han sido los principales y más rentables cultivos de la CGRAA, siendo también los que mayor agua consumen junto con el arroz y los frutales y presentando un alto rendimiento económico, muy superior al de otros cultivos. Aunque estos cultivos son esenciales para la industria agroalimentaria y la actividad ganadera, su demanda no se cubre con los cultivos propios lo que lleva a que se importen grandes cantidades del exterior o de otras regiones (véase Sánchez-Chóliz, 2007 [162]).

Más aún, a pesar de la relevancia e interés económico de estos dos cultivos, en esta última década se ha observado un cambio en los patrones de cultivo hacia productos menos exigentes de agua, como la cebada y el trigo. Ello se ha debido a diversas causas, pero quizás la más relevante ha sido la insuficiencia de las dotaciones de agua suministrada y la inseguridad en su suministro con la regulación actual. Sin duda la política de la PAC, y en particular el desacoplamiento de las subvenciones de la PAC (a partir de 2006) han influido en estos cambios, al depender muy poco las subvenciones de la superficie y por consiguiente, del producto concreto que se cultiva y de su valor. También los cambios en los precios de venta (ejemplo la caída del precio del maíz en 2008) y el encarecimiento de materias primas como abonos han influido. Pero estos dos últimos hechos han sido menos determinantes que los problemas de la falta de agua, ello explica que los cambios se hayan acelerado sobre todo en 2005 y 2008, los dos años de mayor sequía.

De lo visto anteriormente, se pueden obtener algunas recomendaciones que pueden ser de ayuda para mejorar ese marco de decisión. En nuestra opinión, en primer lugar es necesario en el corto plazo finalizar los procesos de modernización, alcanzando en los próximos 10 ó 15 años la eficiencia total del 70%, aunque para ello se deban cofinanciar las transformaciones; sin esta condición toda planificación es muy difícil.

No parece haber tampoco muchas dudas sobre la urgencia de nuevas regulaciones, ya que la garantía de agua para los riegos actuales es muy baja, como demuestran los fuertes déficits registrados especialmente los últimos años secos. Pero estas nuevas regulaciones deberían limitarse a lo ya previsto, pantano de Biscarrués y Balsa de regulación de Almudévar, porque las capacidades de las cuencas del Gállego y Cinca están cerca de sus límites y también por los impactos medioambientales y sociales. No obstante, esta mayor capacidad de regulación no debería usarse para extender el regadío, que ya supera en estos momentos las 130.000 hectáreas, sino para consolidar los existentes, aumentar las garantías de suministro y crear algún tipo de regulación plurianual. Sólo así cultivos como la alfalfa o el maíz, que son muy rentables y necesarios económicamente, volverán a recuperar su papel y no serán desplazados por cereales como el trigo o la cebada. Más aún, la existencia de una mayor garantía de riego favorecerá la ampliación de otros cultivos como frutales u hortalizas, que tienen un gran valor añadido. Debería por tanto promoverse una moratoria sobre la extensión de los regadíos futuros, limitando el regadío al existente, unas 130.000 hectáreas; es la única manera de evitar frustraciones en las expectativas creadas tanto a los agricultores como al conjunto de la sociedad. Más aún, debería también realizarse una política de retirada de las tierras del regadío más problemático (mala calidad de la tierra, alta salinidad, o costes energéticos muy elevados), retirada que se justifica en la baja rentabilidad de esas tierras o en el fuerte impacto medioambiental.

Indudablemente para llevar adelante estos cambios se necesita el apoyo de los interesados y un cierto consenso social. Ello es muy importante, pero no debe tampoco olvidarse que el tiempo en Economía también importa, los cambios son urgentes y no esperan.

1.2.6. Anexo

Tabla 1.13. **Evolución de los niveles de eficiencia por comunidades. En porcentaje**

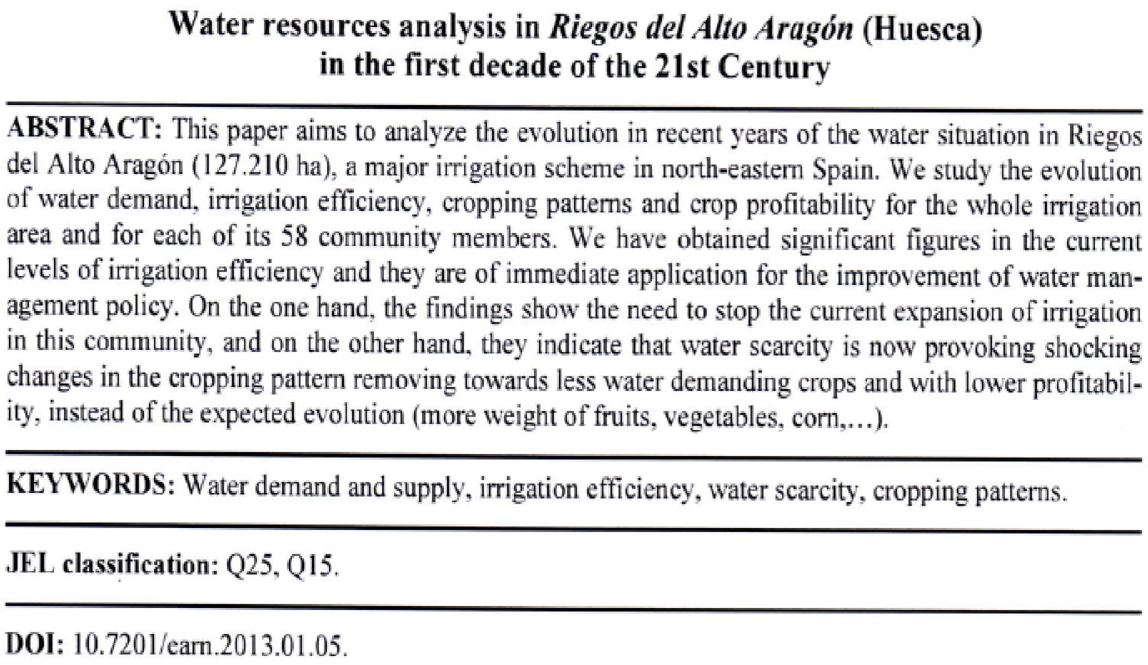
Comunidades de regantes	**Tipo de eficiencia**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	***Promedio***
TARDIENTA	Total	83	76	100	85	79	84	76	*	60	68	*81*
	En baja	100	89	100	96	95	96	86	*	83	75	*92*
TORRALBA DE ARAGON	Total	60	63	70	67	96	89	79	76	35	*	*75*
	En baja	71	73	80	77	100	100	89	87	48	*	*85*
ALMUDEVAR	Total	39	41	45	47	64	57	53	67	*	81	*55*
	En baja	46	48	52	53	78	65	60	76	*	89	*63*
EL TEMPLE	Total	33	32	33	32	55	41	34	33	23	31	*35*
	En baja	39	38	38	37	66	47	39	38	31	34	*41*
GURREA DE GALLEGO	Total	32	32	35	36	57	41	39	39	26	37	*38*
	En baja	38	37	40	42	69	48	45	45	36	40	*44*
LLANOS DE CAMARERA	Total	86	75	74	65	93	70	54	41	24	32	*61*
	En baja	100	89	86	75	100	80	62	47	33	35	*71*
JOAQUÍN COSTA	Total	47	50	51	52	92	67	57	62	35	45	*56*
	En baja	56	59	59	60	100	77	64	70	48	49	*64*
COLLARADA 1ª SECCIÓN	Total	75	83	92	83	*	82	81	97	81	*	*83*
	En baja	89	97	100	95	*	94	92	100	100	*	*95*
COLLARADA 2ª SECCIÓN	Total	71	73	80	75	83	75	75	83	47	51	*71*
	En baja	85	85	91	85	100	87	85	95	65	55	*83*
CARTUJA-SAN JUAN	Total	38	43	46	44	68	50	37	41	32	40	*44*
	En baja	46	51	53	50	82	58	42	47	44	44	*51*
LANAJA	Total	38	43	43	41	59	67	41	51	34	46	*46*
	En baja	45	51	50	47	71	77	47	58	47	50	*54*
ORILLENA	Total	50	58	54	53	76	59	26	36	38	47	*50*
	En baja	60	68	62	60	92	68	29	41	52	51	*58*
SECTOR VIII MONEGROS	Total	50	49	52	51	76	60	50	56	45	83	*57*
	En baja	59	57	60	58	92	69	57	64	62	91	*67*
LALUEZA	Total	60	64	77	72	98	75	85	*	*	*	*76*
	En baja	72	75	88	82	100	86	96	*	*	*	*86*
ALBERO BAJO	Total	50	57	63	42	72	51	53	43	49	66	*55*
	En baja	59	66	73	48	86	59	60	49	67	72	*64*
ALMUNIENTE	Total	56	65	72	62	100	79	64	80	59	73	*71*
	En baja	67	76	83	71	100	91	73	91	80	80	*81*
BUÑALES	Total	68	51	63	40	75	51	53	43	49	66	*56*
	En baja	81	60	73	45	91	59	60	49	67	72	*66*
CALLEN	Total	57	63	63	59	75	59	55	54	60	60	*60*
	En baja	68	73	72	68	90	67	62	61	55	65	*68*
GRAÑEN-FLUMEN	Total	69	75	88	76	98	83	75	74	54	68	*76*
	En baja	82	88	100	87	100	95	85	84	75	74	*87*
SANGARREN	Total	89	77	86	76	*	80	*	*	66	78	*79*
	En baja	100	90	99	87	*	92	*	*	91	85	*92*
SECTOR VII FLUMEN	Total	72	67	73	67	81	65	59	63	48	61	*66*
	En baja	86	78	84	77	98	75	67	71	66	66	*77*
SECTOR X FLUMEN	Total	65	64	68	62	77	67	52	61	43	53	*61*
	En baja	77	74	77	71	93	77	59	70	60	58	*72*
SECTOR XI FLUMEN	Total	46	52	47	47	79	63	49	71	56	67	*58*
	En baja	55	61	54	54	96	73	55	80	77	73	*68*

Comunidades de regantes	**Tipo de eficiencia**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	***Promedio***
SODETO-ALBERUELA	Total	73	76	59	55	67	67	54	56	44	54	*60*
	En baja	87	88	67	63	80	77	61	64	60	59	*71*
TORRES DE BARBUES	Total	65	71	72	66	*	99	70	93	59	52	*72*
	En baja	77	83	82	75	*	100	80	100	81	57	*82*
TRAMACED	Total	82	80	81	72	88	*	82	*	*	*	*81*
	En baja	98	94	93	81	100	*	93	*	*	*	*93*
VICIEN	Total	32	35	50	43	76	52	64	56	34	43	*49*
	En baja	38	42	58	49	92	60	72	63	46	48	*57*
BARBUES	Total	48	49	48	46	75	54	47	46	29	45	*49*
	En baja	58	58	55	53	91	62	53	53	40	49	*57*
CANDASNOS	Total	60	60	70	70	96	67	66	58	50	61	*66*
	En baja	71	71	80	79	100	77	75	66	68	67	*75*
LA SABINA	Total	74	72	72	69	88	48	55	66	53	61	*66*
	En baja	89	85	83	79	100	56	63	74	72	66	*77*
MONTESNEGROS	Total	61	67	64	66	100	73	65	63	46	58	*66*
	En baja	73	79	74	75	100	84	73	72	63	63	*75*
SAN MIGUEL	Total	45	62	59	64	95	64	48	54	44	59	*59*
	En baja	54	72	68	72	100	73	55	61	60	64	*68*
ALCONADRE	Total	54	55	55	57	66	73	63	61	49	61	*59*
	En baja	65	64	63	65	79	84	72	69	67	67	*70*
LASESA	Total	55	57	59	57	74	75	60	52	*	52	*60*
	En baja	65	67	67	64	89	86	68	59	*	57	*69*
LA CAMPAÑA	Total	46	56	44	47	63	80	59	70	49	59	*57*
	En baja	55	65	51	54	77	92	67	80	68	65	*67*
LAS ALMÁCIDAS	Total	65	64	73	69	91	64	58	80	53	62	*68*
	En baja	78	76	84	78	100	74	65	91	73	67	*79*
MIGUEL SERVET	Total	57	65	73	83	100	65	62	70	54	58	*69*
	En baja	68	76	84	95	100	74	70	79	75	64	*78*
SAN PEDRO	Total	63	55	61	48	65	56	66	56	38	46	*55*
	En baja	75	64	70	54	79	65	74	63	53	51	*65*
SANTA CRUZ	Total	50	49	53	52	84	55	48	55	38	47	*53*
	En baja	59	57	60	60	100	63	55	63	53	51	*62*
VAL DE ALFERCHE	Total	68	72	83	75	77	89	73	89	62	73	*76*
	En baja	81	84	95	85	93	100	82	100	85	80	*89*
A-19-20	Total	59	56	59	58	77	82	62	74	56	68	*65*
	En baja	71	66	68	66	93	94	71	84	77	74	*76*
LA CORONA	Total	98	87	100	98	87	74	68	74	60	86	*83*
	En baja	100	100	100	100	100	85	77	84	83	94	*93*

**No se incluyen estos años por falta de fiabilidad de los datos.*

Fuente: Elaboración propia con datos de la CGRAA.

1.3. English version of Sánchez-Chóliz and Sarasa (2013)



Water resources analysis in *Riegos del Alto Aragón* (Huesca) in the first decade of the 21st Century

ABSTRACT: This paper aims to analyze the evolution in recent years of the water situation in Riegos del Alto Aragón (127.210 ha), a major irrigation scheme in north-eastern Spain. We study the evolution of water demand, irrigation efficiency, cropping patterns and crop profitability for the whole irrigation area and for each of its 58 community members. We have obtained significant figures in the current levels of irrigation efficiency and they are of immediate application for the improvement of water management policy. On the one hand, the findings show the need to stop the current expansion of irrigation in this community, and on the other hand, they indicate that water scarcity is now provoking shocking changes in the cropping pattern removing towards less water demanding crops and with lower profitability, instead of the expected evolution (more weight of fruits, vegetables, corn,…).

KEYWORDS: Water demand and supply, irrigation efficiency, water scarcity, cropping patterns.

JEL classification: Q25, Q15.

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1.3.1. Introduction

Throughout the twentieth century, Spanish irrigation water management was characterised by a predominance of supply-side models to satisfy demand for different uses, and by increasing regulation and the ability to control the use of water resources (Pinilla, 2008 [144]). Another essential feature of this century was the rapid growth of the irrigated area, which spread from approximately 40 million hectares of irrigated land in the world in 1900 to 274 million in 2000 (Federico, 2005 [75]).

This expansion of irrigated land has played a crucial role in the development and growth of Spanish agriculture, particularly since the 1960s, providing a basic food supply while allowing food diversification and an increase of agricultural and agri-food exports. This expansion was possible due to rising productivity in irrigated areas, which meant that a smaller rural population could supply food to a growing urban population, (INE, 1965-1989 [97]). In fact, one hectare of irrigated farmland produces six times more than one hectare of non-irrigated land and generates four times as much income (MARM, 2008 [126]).

The Ebro is the largest river basin in Spain, accounting for 17% of its land, and Spain is one of the most important countries in the world in terms of the area under irrigation.[15] The growth of water infrastructure and irrigation expansion occurred earlier in the Ebro basin than in other parts of Spain. However, the expansion of irrigation systems slowed sharply in the last two decades of the twentieth century at the same time as in the rest of Spain, and in line with the international trend (Pinilla, 2008 [144]). Within the Ebro river basin itself, irrigation in the province of Huesca totals over 200,000 hectares, representing almost 40% of the utilised agricultural area (UAA) in Huesca and 6% of the utilised agricultural area in Spain (MARM, 2010 [127]). Irrigated farming output in Huesca accounts for approximately 80% of total agricultural production in the province (DGA, 2009 [56]).

The sustainability of an irrigation growth model based on continuous increases in the water supply first began to be questioned in the latter decades of the twentieth century, and the debate goes on to this day, incorporating new issues such as efficiency, cost-benefit analysis of new interventions and demand management (see Pinilla, 2008 [144]; Gleick, 2000 [81]; Schoengeld and Zibelman, 2007 [169]). Some studies, such as

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[15] In 2009, Spain ranked fourteenth country in the world by irrigated hectares (FAO, 2009 [75]). Spanish irrigation accounts for 1.34% of the world's total.

Barros *et al*. (2011 [20]), show that there is still too little information available about the evolution of the levels of efficiency and cropping patterns in the different irrigation systems of Spain.

This study thus aims to tackle two objectives at the same time: to analyse the water situation in one of the most ambitious irrigation systems in Spain (see Silvestre and Clar, 2010 [172]), specifically, the Upper Aragon Irrigation Scheme (CGRAA in the Spanish acronym) in the first decade of the twenty-first century, and to consider the main characteristics of management and water use efficiency levels. Optimum water management is important because of the major investments required to modernise irrigation systems and raise productivity. Such expenditures thus only make sense if farmers can recover costs through production and if the water supply is sufficient and guaranteed.

In this light, the key question is: Does the CGRAA have a sufficient water supply to embark upon a process of modernisation, while absorbing costs and consolidating output in the foreseeable future? We also endeavour to provide relevant information about the current irrigation situation of the CGRAA and its level of modernisation. This information will, it is hoped, prove a valuable aid to decision-making by water management practitioners and politicians alike, at the same time enabling discussion of current and future water use in this region.

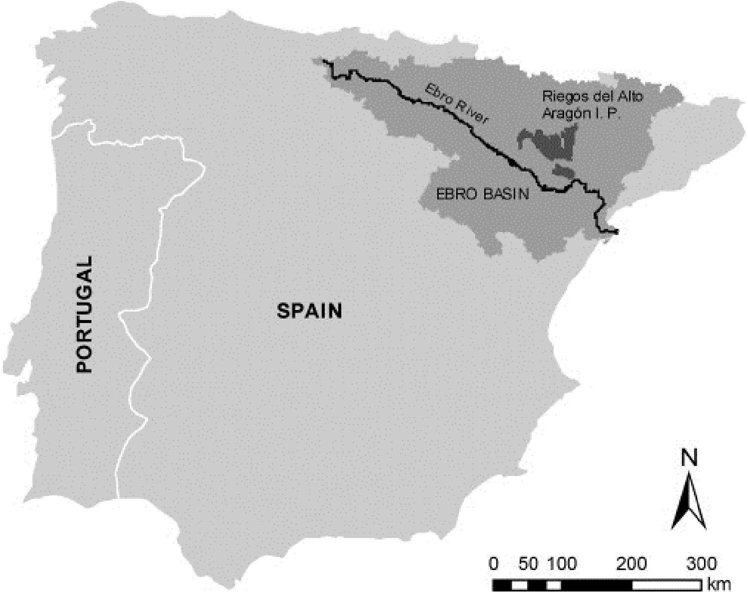
A number of earlier studies of levels of water efficiency in specific irrigation schemes in this region exist, including Tedeschi *et al*. (2001 [177]) for 1,000 hectares in Monegros II; García *et al*. (2009 [79]) for 95 hectares; and Playán *et al*. (2000 [145]) on the Almudévar irrigation sub-scheme, which belongs to the CGRAA. This research aims to go further and analyse the uses and efficiencies of the whole CGRAA, covering more than 125,000 irrigated hectares, and of each of its 58 member irrigation sub-schemes. For this purpose, we use recent data, allowing us to extend the conclusions of earlier studies to the first decade of the twenty-first century.

Following this introduction, the next section provides a brief presentation of the Upper Aragon Irrigation Scheme, in order to throw light on the analysis and evolution of water demand, at the same time as explaining the source of the data used. In section 3, we obtain the levels of water use efficiency which will allow us to quantify crop water requirements and to estimate possible water deficits. The fourth section examines the evolution of cropping patterns and profitability of the main crops. Finally, we end with our conclusions, and some final reflections which may be of use in the design of new water management measures.

1.3.2. Water demand in Upper Aragon: the CGRAA

The CGRAA owns more than 125,000 hectares of land, and supplies water to a number of towns and cities, as well as ten industrial estates. This system includes 58 irrigation sub-schemes which are located mainly between the Monegros Canal and the Cinca Canal. According to approved plans, the final area irrigated could be around 185,000 hectares, which could be added to in the future Hoya de Huesca, Alconadre irrigation schemes and the districts served by the Leciñena irrigation channel, making a total of approximately 200,000 hectares, an area that will be hard to achieve, as we will see, with the current water availability and planned regulations. However, the irrigation system is the largest irrigation scheme currently in the Ebro river basin and, indeed, in the whole of Spain (Map 3.1).

MAP 1.1. **Upper Aragon Irrigation Scheme**



Source: Lecina *et al*. (2010b [105]).

We have been able to make the estimates presented, both for the CGRAA and for each of the irrigation sub-schemes, because we have had access to reliable data for each irrigation sub-scheme and year, much of it expressly prepared and provided by the CGRAA. Specifically, the CGRAA furnished data on the actual consumption of each irrigation scheme over 10 years, and for different water uses (irrigation, industry and urban use), water supplied by from the Ebro Water Board (*Confederación Hidrográfica* *del Ebro* or CHE in the Spanish acronym) to the CGRAA, the current status of modernisation in each irrigation sub-scheme, and qualified information about crops. The water requirements were obtained from Martínez-Cob *et al*. (1998 [128]). Finally, we used the structure of irrigated crops by municipalities from the Aragon Regional Department of Agriculture and Food. [16]

Table 1.1, which shows the current situation of the modernisation process in the CGRAA, is based on a part of the information described. As shown, 29,606 hectares were modernised upon transformation into irrigated land and 44,022 hectares have been recently modernised or are close to the end of the modernization process. Meanwhile, agreements to begin the process of modernization cover a further 18% of the total area. This means that more than 76% of the CGRAA's total area will be modernized in the coming years. Furthermore, some modernization work has been carried out on a further 5% of the total area. However, this still leaves some 19% of the CGRAA's total area which has not been modernised and where there are no agreements to do so.

Table 1.1. **Status of modernisation (area and percentage)**

Situation	**Area (Has 2010)**	**%**
Modernised in the current process	44,022	35%
Modernisation agreed	23,057	18%
Modernised upon transformation irrigated land	29,606	23%
Some works completed	6,304	5%
Not modernised	24,220	19%
TOTAL	**127,210**	**100%**

Source: CGRAA.

Modernisation is undertaken individually by each irrigation sub-scheme, on two levels. On the one hand, each scheme modernises its own control and distribution systems (ditches, ponds, pumps, etc.), and on the other hand, farmers must individually adapt their own land. The latter costs are payable entirely by the farmer. Of the rest, 15% of the total cost is currently funded by the European Union, and the remaining 85% will also be directly paid by the farmer in two tranches consisting of a maximum 35% payable in the first 25 years and the remaining 50% from year 26 to year 50. This suggests that modernisation processes are very costly for farmers, whose payments amount to around 40% of the total costs, while payments for water do not exceed 10%

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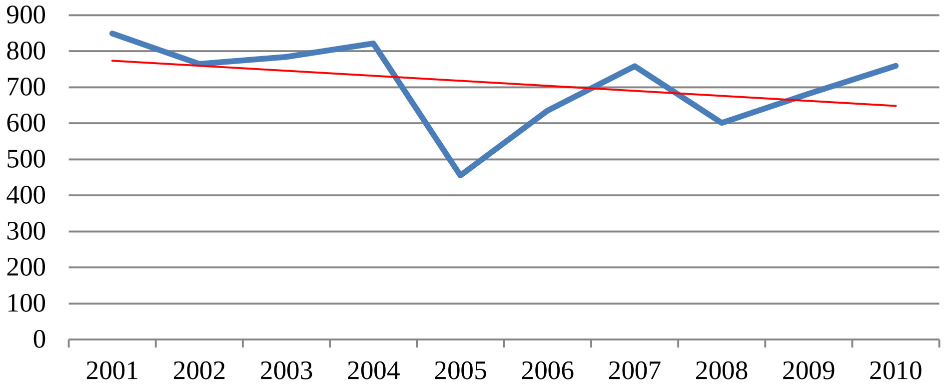
[16] Given its value for use in future studies, this data is freely available and can be downloaded at http://www.credenat.com/

(see Cazcarro *et al*., 2011a [44] and 2011b [45]). To this, we should add the rise in the cost of inputs like fertilisers in the last decade, the impact of drought in 2005 and 2008, and changes in CAP subsidies.

Though undoubtedly burdensome, the payment criteria applied in the recent modernisation, based on the cost recovery criteria established in the Water Framework Directive (WFD, 2000/60/EC [64]), also have one very positive aspect, which is that farmers facing higher payments for water and other rising costs can either sell up or modernise their farms, intensifying production, improving their marketing channels and integrating with the agri-food industry sectors. This has been the dominant response in the CGRAA.

Figure 1.1 shows the evolution of irrigation water use in the first decade of the twenty-first century. In these years, the CGRAA received an annual average of around 710.8 hm³ of irrigation water (Table 1.2), a similar volume to that received towards the end of the twentieth century (Sánchez-Chóliz and Duarte, 2006 [161]). However, Figure 1.1 shows a worrying downward trend, due among other reasons to revegetation around the headwaters of rivers (see Bielsa *et al*., 2011 [25]), the effects of climate change and the lack of multi-annual regulation. In 2005 we may observe a sharp drought-induced fall in the irrigation water supply to almost half the 2001 level. Nevertheless, the water supply in 2006 was higher than in 2005, although it was still below average. The next year, 2007, saw above average water supply, but this was followed by a fresh fall in the level of supply below the average, where it remained in 2009.

Figure 1.1. **Evolution of irrigation water use on fields (Hm^3)**



Source: Own work based on CGRAA data.

Irrigation water use in the CGRAA accounts for almost 98% of total uses. In recent years, however, the share of irrigation use has decreased slightly while industrial and urban uses have risen (Table 1.2). In 2005, which was the driest year in the region since the Spanish Meteorological Agency began measurements in 1947 according to AEMET (2005 [2]), the volume of irrigation water use was considerably reduced, while industrial and urban uses increased. This reveals the rigidity of industrial and urban uses as opposed to farming use, possibly caused by regulatory preference for urban versus irrigation uses.

Table 1.2 also shows the evolution of the water supplied annually to the CGRAA by the CHE from its reservoirs. The average water supply was 847.7 hm^3 of regulated water, which were used to irrigate more than 115,000 hectares with high irrigation priority in 2001, and over 121,000 hectares in 2010. If land in which the availability of irrigation water is precarious, a total of 127,210 hectares were supplied in 2010. As we have seen, the volume of water supplied displays a gradual, but not uniform, downward trend.

Table 1.2. **Water demand and supply in the CGRAA**

Year	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	***On average***
Hectares with high irrigation priority (Monegros II included)	115,933	116,259	116,647	119,985	121,410	119,995	121,284	121,606	121,503	121,896	
Total hectares	123,049	123,969	124,311	124,795	125,547	125,790	128,974	126,539	127,124	127,210	
Water supply from reservoirs (Hm^3)	1,025.2	909.1	912.2	949.0	565.7	747.7	874.7	696.3	949.2	847.6	847.7
Urban water demand (Hm^3)	8.3	8.5	9.4	9.8	10.4	10.4	9.9	9.6	13.0	11.9	*10.1*
% water supply from reservoirs	*0.81*	*0.94*	*1.03*	*1.04*	*1.84*	*1.39*	*1.13*	*1.38*	*1.37*	*1.40*	*1.2*
Industrial water demand (Hm^3)	4.6	5.0	4.6	4.9	5.6	6.3	6.4	5.4	4.6	5.0	*5.2*
% water supply from reservoirs	*0.45*	*0.55*	*0.50*	*0.51*	*0.99*	*0.84*	*0.73*	*0.78*	*0.49*	*0.59*	*0.6*
Irrigation water demand (Hm^3)	848.6	764.4	783.8	821.1	455.2	635.0	758.0	600.8	681.7	759.0	*710.8*
% water supply from reservoirs	*82.77*	*84.09*	*85.93*	*86.52*	*80.46*	*84.92*	*86.65*	*86.29*	*71.82*	*89.54*	*83.90*
Irrigation, urban and industrial water demand (Hm^3)	861.5	778.0	797.8	835.8	471.2	651.7	774.2	615.8	698.7	775.9	*726.1*
% conveyance efficiency	*84.03*	*85.57*	*87.46*	*88.07*	*83.29*	*87.16*	*88.51*	*88.44*	*73.68*	*91.53*	*85.77*
Water losses in transport from reservoir to field (Hm^3)	163.7	131.2	114.4	113.3	94.5	96.0	100.5	80.5	253.3	71.8	*121.9*
% conveyance losses	*15.97*	*14.43*	*12.54*	*11.93*	*16.71*	*12.84*	*11.49*	*11.56*	*26.32*	*8.47*	*14.23*
Average irrigation water demand (m^3/ha with high irrigation priority)	8,732	7,703	7,700	7,787	4,528	6,092	7,078	5,602	7,695	6,815	*6,973*

Source: Own work based on CGRAA data.

To begin with, we may note that the increasing water supply available in the twentieth century of increasing the water supply is not in line with the observable facts in the first decade of the twenty-first century in the CGRAA, see the previous works of Faci *et al*. (2000 [71]) and Playán *et al*. (2000 [145]), who concluded that the current distribution system for irrigation water in the CGRAA would not be able to provide a flexible and guaranteed water supply to farmers. As these authors point out, the irrigation systems were originally built to winter crops, so that the switch made at the end of the last century to more intensive crops which need water mainly in spring and summer, increased water requirements by reducing the ability of the system to cope and guarantee of water supply.

Moreover, the area of irrigated land has increased. Specifically, high priority irrigated land has increased by more than 5,963 hectares since 2001, although expansion peaked at the end of twentieth century with an increase of around 96,666 hectares in 1994 (see Sanchez-Chóliz and Duarte, 2006 [161]). In the last fifteen years irrigated land in the CGRAA increased by around 30,000 hectares, while a shrinking volume of water is being used to irrigate an area that already exceeds 130,000 hectares and continues to expand. As a result, irrigation water demand on reservoirs averages some 6,973 m^3/ha per year, but in 2005 and 2008 the figure was much lower (4,528 m^3/ha and 5,602 m^3/ha respectively).

Table 1.2 also shows that average water demand is 726.1 hm^3 for irrigation, industrial and urban water uses. It is assumed that average conveyance efficiency from the reservoir to the field is 85.77% and that water losses in transport are approximately 14.23%. Except in 2009 there has been a clear upward trend in conveyance efficiency, which rose from 84.03% in 2001 to 91.53% in 2010. Meanwhile, water losses in 2009 arose because the volume of water supplied from reservoirs was higher than the volume that was actually required, partly because of significant winter precipitation, and partly because of surplus water in reservoirs led to significant discharges.

To conclude, we may affirm that the decreasing irrigation water supply observable in the CGRAA is not in line with the upward water supply seen in the latter decades of the twentieth century. Meanwhile, the area irrigated land is still expanding, as it did in the twentieth century. This is only possible because of significant progress in modernisation, which has involved important changes in crops, costs and business structures. These facts form the basis for our conjecture that the water supplied to irrigate land in the CGRAA is being used with increasing efficiency.

1.3.3. Water requirements and irrigation efficiency

Before we can estimate the level of irrigation water efficiency, we need to estimate the net water requirements of each crop based on the areas where they are grown. The net water requirement is the volume of water per hectare required for each crop to survive. In other words, it is the additional water that the crop requires above the average monthly rainfall. The 58 irrigation sub-schemes of the CGRAA are located in six different areas, Monegros, Hoya de Huesca, Somontano Barbastro, Zaragoza, Bajo Cinca and Cinca Medio. As the available information about water requirements for the crops is broken down by district (see Martínez-Cob *et al*., 1998 [128]), the geographical relationship between irrigation schemes and districts allows us to obtain the water requirements of each crop in each irrigation sub-scheme and, consequently, the volume of water required in each. The results based on monthly data and average climatic conditions are presented in Table 1.3.

Maize, rice, alfalfa and fruit trees require the largest volume of water, while crops like wheat, barley and legumes require the least.

Table 1.3. **Net water requirements in m³/ha**

Crops	**Monegros**	**Hoya de Huesca**	**Zaragoza**	**Somontano de Barbastro**	**Bajo Cinca**	**Cinca Medio**	**Weighted average**[17]
Wheat	2,420	1,890	2,480	2,140	2,610	2,375	*2,309*
Barley	2,050	1,570	2,090	1,520	2,230	1,943	*1,900*
Maize	5,520	4,940	5,900	5,040	5,760	5,405	*5,372*
Rice	8,450	7,840	8,145	8,145	8,145	8,145	*8,282*
Oats	4,678	4,102	4,713	4,207	4,825	4,825	*4,542*
Other cereals	4,950	4,270	4,950	4,190	5,380	3,438	*4,643*
Industrial crops	4,850	4,370	5,000	4,260	5,060	4,647	*4,686*
Legumes	1,335	1,335	1,335	1,335	1,335	1,335	*1,335*
Potatoes	4,455	4,455	4,455	2,935	2,935	2,935	*4,045*
Green alfalfa	6,610	5,440	7,010	5,530	7,190	6,310	*6,286*
Other forage plants	3,880	3,295	4,235	3,340	4,170	3,730	*3,721*
Vegetables	3,717	3,717	3,717	3,542	3,542	3,542	*3,670*
Fruit trees	6,287	5,489	7,023	5,489	7,085	6,287	*6,093*
Almond trees	5,300	5,300	5,300	5,300	5,300	5,300	*5,300*
Olives	2,880	2,880	2,880	2,880	2,880	2,880	*2,880*
Vineyards	4,730	4,730	4,660	4,730	4,730	4,730	*4,729*

Note: We have not treated total runoff, percolation, evaporation and wind losses as irrigation losses, and we therefore do not include them in water requirements. Efficiency levels will necessarily be higher if these losses, and especially deep percolation and evaporation from the land, are not considered.

Source: Own work based on Martínez-Cob *et al.* (1998 [128]).

1.3.3.1. Levels of efficiency

Losses occur in irrigation systems as a result of transport to the field and in farming processes. We shall therefore define and analyse three types of efficiency: field application efficiency, total efficiency and conveyance efficiency. These efficiencies are defined by the following expressions:

$$Field\ application\ efficiency\ ^{18} = \frac{net\ crop\ water\ requirements}{water\ application\ in\ the\ field} \qquad \text{Eq. (1.1)}$$

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[17] It is weighted following the share of each area in the irrigated land in the CGRAA in 2010.

[18] Field application efficiency is not usually considered in the literature. It is a measure of the water deficit of the crop and the efficiency of irrigation technologies. It could, therefore, be disaggregated into the result of the ratio of crop water requirements to water applied to the crop, a measure of the crop water deficit, and the ratio of water applied to the crop in each plot divided by the water it receives, measuring the efficiency of the irrigation system. For the sake of simplicity, however, the concept of field application efficiency has not been broken down because this would not affect the final objective, deficit estimates or conclusions.

$$Conveyance\ efficiency\ = \frac{water\ application\ in\ the\ field}{water\ from\ reservoirs} \qquad \text{Eq. (1.2)}$$

Therefore:

$$Total\ efficiency = $$
$$field\ application\ efficiency \times\ conveyance\ efficiency \qquad \text{Eq. (1.3)}$$

As we have seen in Table 1.2, the average level of conveyance efficiency for the decade is around 85.77%, a high percentage which displays an increasing trend except in 2009. An accurate estimate of other efficiencies in the CGRAA would require data on water uses and demand in each of its 58 irrigation sub-schemes. This study only includes 45 irrigation schemes over the last ten years, although they represent 98% of the total irrigated land in the Upper Aragon Irrigation Scheme, so our estimates are robust and can be considered representative of the CGRAA's actual situation.

First, we analyse the distribution of irrigated land by crop type in each irrigation scheme in order to estimate the level of efficiencies based on the distribution of irrigated land by municipalities obtained from DGA (2011a [57]). Second, after obtaining the number of hectares of each crop, we multiply this area by the net water requirements of each crop shown in Table 1.3 to obtain the volume of water required by crops in each irrigation scheme, taking into account the average precipitation in each area but without considering water runoff, deep percolation and other losses.

Table 1.4 summarises the levels of field application and total efficiency. The results for each irrigation sub-scheme are shown in the Annex.[19] The average total efficiency in the CGRAA schemes analysed was 61% over the last ten years, assuming that the water was set aside for hectares with high irrigation priority.[20] If we assume that the total hectares of the CGRAA are irrigated, the efficiency level is 62%. Taking into account that the average loss from the transportation of water from the reservoir to the

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[19] The table in the Annex presents the levels of field application and total efficiency by irrigation schemes reaching 100%, especially in the column for 2005. These figures refer to precarious irrigation which uses amounts of water below plant needs and leads to efficiency levels above 100% according to the previous definition. In any case, the upper levels of efficiency used for our estimates are never above 100%, and they match those shown in the table in the Annex in order to correct the bias produced by precarious irrigation.

[20] Two decades ago, the Food and Agriculture Organization of United Nations (FAO) found that levels of total efficiency between 50 and 60% could be rated as "good efficiency" (see FAO, 1989 [72], Appendix I).

field is 14.23%, field application efficiency is 72% on average in the CGRAA over the decade, considering land with high irrigation priority, and 73% assuming the irrigation of all fields. These levels represent efficient irrigation water use, although it could be improved, especially if deep percolation, wind drift and evaporation, which can be as high as 9.5% in Huesca (MARM, 2001 [125]), are treated as losses in the application. Furthermore, the share of woody crops is not high in the CGRAA, representing less than 3% of the total area, and in the short term a radical change towards woody crops in the cropping pattern is not expected. The transformation which this entails becomes clear when it is recalled levels of total efficiency were around 45% three or four decades ago.

Table 1.4. **Levels of field application and total efficiency (2001-2010)**

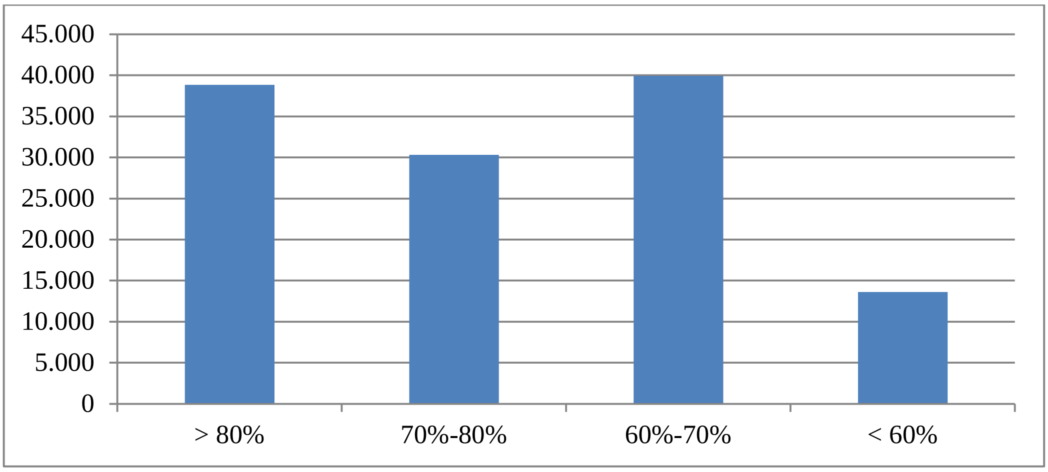
	Hectares with high irrigation priority	Total hectares
Field application efficiency	72%	73%
Total efficiency	61%	62%

Source: Own work based on CGRAA data.

The results here are the same as those reported in previous studies estimating the level of efficiency in the Alto Aragon districts. Tedeschi *et al.* (2001 [177]) estimated efficiency levels of 60% in the late twentieth century in the area of Monegros II. Playán *et al.* (2000 [145]) reported average levels of 62% at the beginning of twenty-first century, obtaining better results in some areas with levels of field application efficiency of 77%. In more recent works, Garcia *et al.* (2009 [79]) estimate average levels of irrigation efficiency of 73% in Bárdenas Canal irrigation scheme no. V, which is near the CGRAA. This study therefore confirms these partial results, filling gaps and giving estimates of levels of irrigation efficiency and uses in the CGRAA, and for each irrigation sub-scheme.

Figure 1.2 classifies the irrigated area according to the level of field application efficiency obtained. Almost one third of the irrigated land in the CGRAA has a field application efficiency above 80%. Another 25% of the area is between 70% and 80%, which means that more than 50% of the total area of the CGRAA has good field application efficiency levels. Let us not forget, meanwhile, that these irrigation systems are open and greenhouses are not used. Only 11% of the area has field application efficiency levels below 60%. It is on this land, and on a further third of the total with field application efficiency levels of between 60% and 70%, that modernisation policy should focus, as these results, and the gains made compared to the situation a few decades ago, were made possible by the recent modernisation processes undertaken (Table 1.1).

Figure 1.2. **Hectares with high irrigation priority according to the level of the field application efficiency**



Source: Own work based on CGRAA data.

1.3.3.2. Evolution of the levels of efficiency

Table 1.5 shows the annual evolution of conveyance, field application and total efficiency over the last decade, revealing a gradual upward trend in all three efficiency levels. This is due to adoption of improved irrigation techniques encouraged by the slow decline in the volume of water available and the increase in the irrigated area. , The observable increase in the water deficit, in 2005, the driest year of the decade in this region, points to very high efficiency levels of 80% and 96% respectively in field application and in total efficiency. These levels are similar to the results reported for 2005 in García *et al*. (2009 [79]), despite the dip in conveyance efficiency. In 2008, another dry year, the levels of field application and total efficiency rose significantly, but in this case conveyance efficiency also remained high. In 2009 there was a significant drop in total efficiency level, but this was caused rather by an increase in the availability of water than by inefficient use of water in the field. This increase in the volume of available water resulted in discharges from reservoirs, thereby lowering the level of conveyance efficiency.

Table 1.5. **Annual evolution of the three levels of efficiency**

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	*On average*
Conveyance	84%	86%	87%	88%	83%	87%	89%	88%	74%	92%	*86%*
Field application	66%	68%	69%	66%	96%	78%	65%	71%	71%	65%	*72%*
Total	55%	58%	60%	58%	80%	68%	58%	63%	52%	59%	*61%*

Source: Own work based on CGRAA data.

1.3.3.3. Is enough water available to irrigate crops?

Having established the levels of efficiency and water requirements for each crop, we can now examine whether the volume of water supplied to the CGRAA, which displays a gradual downward trend, is sufficient for irrigation purposes, or if there is a water deficit. As reported in Table 1.2, the water supply from reservoirs was 6,973 m^3/ha on average over the last ten years, so the average water supply based on a total efficiency level of 61%, will therefore be 4,254 m^3/ha. According to Table 1.3, however, 4,254 m^3/ha is insufficient in all districts of the CGRAA system to irrigate crops such as maize, rice, industrial crops, potatoes, alfalfa, fruit trees, almonds and vineyards. If total efficiency were raised to 70%, the same 6,973 m^3/has, would provide a water supply of 4,881 m^3/ha, which would still be insufficient for maize, rice, alfalfa, fruit trees and almonds in all districts. Consequently, even in an average year it is impossible to irrigate the total surface to grow maize, rice, alfalfa, fruit trees and almonds, which are the most profitable crops and are of great interest given their key role in the agri-food industry, the production of feed and trade. Growing these products is possible only if they are combined with other less thirsty, but also less profitable, crops like wheat, barley, legumes, olives (Tedeschi *et al*., 2001 [177]). The introduction of thirstier but more profitable crops in the CGRAA, which would help defray costly modernisation, may therefore be limited due to the scarcity and insecurity of water supplies, regardless whether the crops concerned are economically viable and in demand in domestic and international markets.

The results show on the one hand that the water supply is insufficient in the current situation, and on the other hand that improvements in the level of efficiency with which water is used are thanks to irrigation modernisation. The latter option is without doubt important, but it is clearly limited because some losses, like deep percolation, are inevitable, or at least very difficult to reduce. If, as we have seen, transport losses are about 15% and losses due to deep percolation, evaporation and wind drift on application can reach 9.5% (MARM, 2001 [125]), levels of field application efficiency higher than 85% and total efficiency exceeding 70% would be very difficult to achieve.

On the other hand, if modernisation processes end and all irrigation reaches a field application efficiency level of 70%, water savings would be only 90 hm^3 without changing crops according to our data. This figure is lower than the deficits found, as we shall see below. Moreover, modernisation in general does not actually really save any water, because the savings achieved are absorbed by crop intensification and changes in use. Finally, certain characteristics of the CGRAA, such as long irrigation periods, small fields and difficult irrigation management on summer nights, would also make it difficult to improve efficiency levels much further (Lecina *et al.*, 2010a [104]).

We shall now seek to quantify the water deficit under current conditions, under the assumption of the 2001 cropping pattern in the first place, the average cropping pattern for the period from 2001 to 2010 in the second. The former scenario reflects the situation in the year with the highest demand for water per hectare in the period examined, mainly due to the greater presence of alfalfa and maize. This could be considered a rough approximation to the ideal cropping pattern without water constraints. The results are shown in Table 1.6. The latter scenario describes the average situation, and it is clearly influenced by the adjustments made by farmers using the information available at the beginning of the water campaign. The results are shown in Table 1.7. In this case, the average crop distribution used is far from optimal, as we shall see later.

Both tables compare the volume of water required to cover irrigation water requirements [21] with levels of total efficiency of 60% and 70% (the demand required in both tables), and the volume of water actually supplied to the CGRAA in the years concerned. The difference between these volumes reflects the water deficit or availability. Positive results indicate that the volume of water demand exceeded the supply, representing a deficit, while negative values indicate that the volume of water supplied fully covered requirements. We may note here that raising the level of

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[21] Based on the average water requirements obtained in Table 1.3.

efficiency results in smaller deficits or even surpluses (smaller positive or negative figures), or in larger surpluses (larger negative figures).

Table 1.6 shows that the volume of water supplied from reservoirs would have been insufficient to cover the water demand required in all years except in 2001 given a total efficiency level of 60% (similar to the current actual level). This is because the volume of water supplied from reservoir was exceptionally high in 2001, and even exceeded demand by 49 hm^3. An additional volume of 430.6 hm^3 would have been needed in 2005. If the level of total efficiency is raised to 70%, the volume of water supplied would have been enough for some years (2001, 2002, 2003, 2004 and 2009), but in five years (2005, 2006, 2007, 2008 and 2010) it would still fail to cover crop requirements. The latter years are, of course, those which suffered water deficits (except in 2009), due to the reduced availability of water and specifically to the constant expansion of irrigated land. These results also reveal the insecurity of the water supply, a factor that is almost as important as the supply itself in terms of economic performance.

Table 1.6. **Water requirements in the CGRAA for the 2001 cropping pattern**

		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
	Water requirements	586	590	592	594	598	599	614	603	605	606
	Hm^3 water supply	1,025	909	912	949	566	748	875	696	949	848
Level of efficiency 60%	Water demand	976	984	986	990	996	998	1,023	1,004	1,009	1,009
	Water deficit (Hm^3)	-48.7	74.7	74.3	41.3	430.6	250.5	148.8	307.9	59.6	161.9
Level of efficiency 70%	Water demand	837	843	846	849	854	856	877	861	865	865
	Water deficit (Hm^3)	-188.2	-65.9	-66.6	-100.2	288.2	107.9	2.6	164.5	-84.5	17.7

Source: Own work based on CGRAA data.

If these calculations are analysed for the average distribution of crops between 2001-2010, water deficits are obtained in five of the ten years based on 60% efficiency. However, these deficits are lower than in previous years because of structural shifts towards less thirsty crops.[22] If the level of total efficiency is raised to 70%, a water deficit is observable only in the three driest years, with a water deficit of more than 185

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[22] Let us not forget that farmers, adapt their crops to the likely availability of water on the basis of information obtained at the beginning of the irrigation campaign. This phenomenon is reflected in the average structure of crops and lower water demand.

hm^3 in 2005. However, this assumes not only total efficiency of 70% but also a significantly less profitable crop structure than would be desirable.

Table 1.7. **Water requirements in the CGRAA for the average 2001-2010 cropping pattern**

		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
	Water requirements	515	519	521	523	526	527	540	530	532	533
	Hm³ water supply	1,025	909	912	949	566	748	875	696	949	848
Level of efficiency 60%	Water demand	859	865	868	871	876	878	900	883	887	888
	Water deficit (Hm³)	-166.5	-43.9	-44.6	-78.1	310.4	130.2	25.4	186.8	-62.0	40.2
Level of efficiency 70%	Water demand	736	742	744	747	751	752	772	757	760	761
	Water deficit (Hm³)	-289.1	-167.5	-168.5	-202.5	185.3	4.8	-103.2	60.7	-188.7	-86.7

Source: Own work based on CGRAA data.

In view of existing plans to expand the area under irrigation to 185,000 hectares, meanwhile, we should also consider whether the current water supply levels are sufficient to cover the water requirements for these crops. Based on the results described above, the answer can only be no. Let us argue this point in detail, however. Table 1.8 presents two scenarios, in the first of which the area irrigated is 150,000 hectares, while in the second scenario it rises to 185,000 hectares. The 2001 cropping pattern is assumed in both scenarios, the water supply is 848 hm^3, equal to the ten-year average in the ten years (Table 1.2). The results show a water deficit of 620 hm³ if 185,000 hectares are irrigated with a total efficiency of 60%, and 410 hm³ if the level of total efficiency is raised to 70%. These figures are lower for 150,000 hectares, but they remain high at 342 hm^3 and 172 hm^3 respectively.

Table 1.8. **Estimated water requirements (Hm³)**

Hectares	150,000		185,000	
Total efficiency level	60%	70%	60%	70%
Water requirements	714	714	881	881
Water demand	1,190	1,020	1,468	1,258
Water supply	848	848	848	848
Water deficit	342	172	620	410

Source: Own work based on CGRAA data.

It is common to claim in answer to the above argument that the solution lies in outstanding irrigation improvements, but this hardly changes the problem as we explain in more detail in the conclusions. The two main outstanding improvements in the CGRAA are Biscarrués reservoir and Almudévar dam, which will eventually provide 35 hm^3 and 169 hm^3, and are clearly insufficient to cover the deficit and ensure irrigation of 185,000 hectares according to Table 1.8. However, they would certainly help reduce it in the 150,000 hectare scenario assuming the modernization process could raise efficiency to the level of 70%. Nevertheless, the values considered here are averages, which means that these improvements would not be enough even for 150,000 hectares in a dry year.

1.3.4. Evolution of cropping patterns

In the previous section we used the distribution of irrigated land by type of crop to understand the volume of water required by crops in the CGRAA. In this section, we analyse whether or not water allocations have caused any change in cropping patterns in recent years. This discussion focuses in particular on the evolution of irrigated land, crop production and profitability.

1.3.4.1. Annual evolution by crop groups

The key issues shaping crop patterns are the availability of water resources, production costs and subsidies, in particular those paid under the Common Agricultural Policy (CAP). Increasing regulation of water resources throughout the twentieth century allowed farmers to introduce crops with higher water requirements (Pinilla, 2006 [143]). In the CGRAA, crops such as winter cereals were reduced to make room for maize, rice and fodder crops in the 1980s (Silvestre and Clar, 2010 [172]). In the districts surrounding the CGRAA, the alfalfa crop increased from 4% to 43.4% of the irrigated farmland in the 1990s (Dechmi *et al*., 2003 [49]).

Table 1.9 shows the annual area of irrigated land planted with the main crops, reflecting the significant changes that have occurred taken place in the distribution of crop areas from 2001 to 2010.

Table 1.9. **Evolution of the land planted with the main crops in the CGRAA (Has)**

Crops	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Wheat	2,489	5,053	4,342	5,719	4,157	5,319	7,346	9,475	5,517	8,162
%	*2.21*	*4.48*	*3.85*	*5.07*	*3.64*	*4.60*	*6.28*	*8.08*	*4.72*	*6.86*
Barley	9,992	12,665	12,469	13,430	14,668	18,825	20,676	31,683	23,175	26,662
%	*8.89*	*11.24*	*11.06*	*11.91*	*12.85*	*16.27*	*17.69*	*27.03*	*19.81*	*22.40*
Maize	40,712	34,978	37,001	35,417	22,688	24,258	26,723	22,361	26,412	23,494
%	*36.21*	*31.03*	*32.81*	*31.40*	*19.88*	*20.97*	*22.86*	*19.08*	*22.58*	*19.74*
Alfalfa	29,253	30,527	31,208	31,459	29,478	30,003	25,838	22,031	26,510	27,921
%	*26.02*	*27.08*	*27.67*	*27.89*	*25.83*	*25.94*	*22.10*	*18.79*	*22.66*	*23.46*
Rice	5,487	5,162	5,245	6,282	4,542	4,631	6,345	4,445	5,717	6,693
%	*4.88*	*4.58*	*4.65*	*5.57*	*3.98*	*4.00*	*5.43*	*3.79*	*4.89*	*5.62*
Industrial crops	9,069	4,349	4,975	3,610	2,271	1,712	1,099	1,759	1,707	864
%	*8.07*	*3.86*	*4.41*	*3.20*	*1.99*	*1.48*	*0.94*	*1.50*	*1.46*	*0.73*

Source: Own work based on data from DGA (2011a [57]).

As we can see, alfalfa remained at the same levels throughout the period, although a gradual downward trend has recently appeared. The area under wheat increased more than three times, in contrast to the trend observable at the end of the twentieth century.

The land planted with barley increased almost threefold, mainly in 2002, 2005 and 2008 which suggests that this change was closely linked to the volume of water supplied, which fell in the three years concerned (Table 1.2). Barley of course provides farmers with greater flexibility because it demands less water and can be successfully grown in the driest years, and some short-cycle barley varieties are sown in winter. The area under maize area shrank from 36.21% of the total area in 2001 to 19.7% in 2010. Sunflowers have almost disappeared, as the expansion of this crop in the 1990s was mainly due to European Community subsidies (Faci *et al.*, 2000 [71]). The area planted with rice is almost fixed, because salinity conditions on much of this land do not favour other crops. Rice also receives specific support from the CAP (Atance *et al.*, 2006 [10]).

In short, the decade 2001-2010 saw significant changes in cropping patterns, including a shift towards barley and wheat, which consume less water. As we shall see, these developments were influenced the availability of water irrigation and the change in the terms of CAP subsidies, which were largely decoupled from crop types in 2006 (Atance *et al.*, 2006 [10]).

1.3.4.2. Profitability of crops

To confirm the above, let us analyse the evolution of crop output in tonnes (see Table 1.10). Barley production tripled, as did wheat. Maize declined, especially in the dry years 2005 and 2008, although it has recovered somewhat in recent years. Meanwhile, alfalfa production declined gradually (approximately 12.5%) between 2001 and 2010, with steeper falls in the dry years of 2005 and 2008, although the fall was smaller than that of decline, output of which shrank by 23.74%, as noted in Barros *et al*. (2011 [20]) and Garcia *et al*. (2009 [79]). This evolution is therefore consistent with the decrease in the availability of water, which is especially evident in drought years.

Table 1.10. **Evolution of production in the province of Huesca (Tn)**

Crops	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Wheat	25,287	58,786	52,710	40,186	33,317	63,917	73,223	87,987	58,786	78,755
% of 2001	*100.00*	*232.48*	*208.45*	*158.92*	*131.76*	*252.77*	*289.57*	*347.95*	*232.48*	*311.44*
Barley	81,712	194,945	128,962	128,005	92,676	194,613	201,488	209,183	194,945	248,098
% of 2001	*100.00*	*238.58*	*157.83*	*156.65*	*113.42*	*238.17*	*246.58*	*256.00*	*238.58*	*303.62*
Maize	565,176	413,711	457,476	551,598	308,848	312,334	394,930	286,243	413,711	431,016
% of 2001	*100.00*	*73.20*	*80.94*	*97.60*	*54.65*	*55.26*	*69.88*	*50.65*	*73.20*	*76.26*
Alfalfa	3,493,542	2,887,924	2,991,207	3,078,500	2,427,515	3,349,808	3,036,080	2,703,786	2,887,924	3,058,924
% of 2001	*100.00*	*82.66*	*85.62*	*88.12*	*69.49*	*95.89*	*86.91*	*77.39*	*82.66*	*87.56*

Source: Own work based on DGA (2011b [58]).

Have possible changes in yields per hectare influenced the evolution of output? A comparison between the figures in Tables 1.9 and 1.10 excludes this possibility, because the value of the tonnage/hectares ratio obtained from both tables over the decade is very similar for wheat and barley, improves very slightly for alfalfa and improves significantly for maize. Therefore, changes in yields cannot explain the observed evolution of cropping patterns based on increases in yields of wheat and barley, and declines in maize and alfalfa. Moreover, comparing the profitability of the main crops in the province of Huesca with the Spanish average (see Table 1.11), we may observe that land characteristics in Huesca favour sowing maize and alfalfa on irrigated land, but output of both actually fell over the decade. The maize yield is on average similar to Spain as a whole, or even slightly higher, and the alfalfa yield is clearly above the

Spanish average. However, yields from other crops like wheat and barley are lower in Huesca than in the rest of Spain, but output has actually grown.

Table 1.11. **Performance of irrigated crops (kg/ha). Average 2001-2008**[23]

Crops	Huesca	Spain
Wheat	4,097	4,375
Barley	4,032	4,190
Maize	9,993	10,106
Rice	5,535	7,098
Sunflower	2,147	1,923
Alfalfa	72,415	59,891

Source: Own work from MARM (2001-08 [123]) and DGA (2011b [58]).

Examination of the financial returns earned on the different crops once again leads to the conclusion that the evolution of cropping patterns depended mainly on water availability and less on profitability. Table 1.12 reflects the gross margin obtained on the main crops in Aragon. These figures reflect monetary flows (sales + subsidies - direct costs) and are one of the basic tools for the decision-making by farmers. The most profitable crops per hectare are alfalfa and maize, but output fell consistently over the decade. Meanwhile, the profitability of wheat and barley declined, but output increased.

Table 1.12 shows a steep fall in the profitability of maize in 2008 followed by a slight recovery in 2009. Nevertheless, the return from this crop remained above the profitability of barley in 2008, and it was above both wheat and barley in 2009. This drop in performance cannot be attributed only to dry conditions, for there was no drought in 2009. Rather, it was due to falling prices and increasing costs caused by the rising price of fertilisers, while maize yields remained stable (kg/ha). This should warn us that not everything can be explained by water availability; the market is very important and plays a key role in irrigated output and marketing.

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[23] 2009 and 2010 data are not available.

Table 1.12. **Evolution of the standard gross margin for irrigated crops (€/ha)**

Crops	2001	2002	2003	2004	2005	2006	2007	2008	2009
Wheat	597.13	737.59	622.09	699.35	601.63	438.16	737.49	549.47	477.49
Barley	436.43	562.91	613.04	517.36	507.38	429.13	689.76	403.87	288.55
Maize	955.94	1,116.45	1,127.31	1,173.17	1,014.35	1,108.05	1,581.82	500.08	724.19
Alfalfa	1,078.87	1,030.12	1,114.02	1,093.39	1,061.67	815.34	1,037.49	1,393.81	1,133.49

Source: MARM (2001-2009 [124]).

In light of the above, we may affirm that the shortage of water in the driest years in the series, like 2005, and the decline in water allocation per hectare in the decade were the main drivers of the reduction in the thirstiest crops, and especially maize, leading farmers to sow less demanding crops like barley and wheat, even though they are less profitable and margins have actually fallen in recent years. This trend intensified in the drought year of 2008 when water constraints were severe, as the profitability of maize fell and because of the shift in the focus of the CAP towards subsidies that do not depend on farm area, and are therefore not dependent on specific crops (uncoupling).

1.3.5. Conclusions

In recent years, the direction of water planning has aroused fierce debate in Spain. The twentieth century was dominated throughout by supply-side models which focused on building infrastructure to meet growing demand for water and allow expansion of the irrigated area. However, the focus has shifted and other principles nowadays take precedence, including efficiency, sustainability and good water status. The irrigation schemes have a key role to play in this context, because their members are the main users of regulated water and earn their income from its use.

This is the context for this study, which discusses the water situation in the Upper Aragon region in the first decade of the twenty-first century, and provides a study of water demand, levels of efficiency in the use of irrigation water, cropping patterns and the profitability of the Upper Aragon Irrigation Scheme, an irrigation system which includes about 2/3 of irrigation in Huesca and includes 58 irrigation sub-schemes.

From a demand-side standpoint, this irrigation system faces a number of issues. On the one hand, it needs to meet increasing urban and industrial demand for water (given the aridity of Aragon as a whole). In both of these cases, elasticity is lower than agricultural demand, although city-dwellers and industry currently represent only a small percentage of total use. On the other hand, the regulated water supplied to the CGRAA by the CHE (Ebro Water Board) clearly declined over the decade covered by the study, and this decline seems likely to be permanent or worse, as the most probable causes are revegetation around the headwaters of rivers and the effects of climate change. This represents a major transformation compared to the situation in the twentieth century, when the water supply and water availability increased enormously. Moreover, the irrigated area in the CGRAA is growing each year and the expected trend based on existing plans is for this growth to continue. All this inevitably oblige both the CHE and the irrigation schemes carefully to rethink water management.

The volume of water supplied to the CGRAA has not increased in the last 20 years (regulation is almost the same as two decades ago), while the irrigated area has grown. These facts can only mean that water is currently used more efficiently than in the last century. It is only in this way that more land can be irrigated with the same water endowments. This is a *leitmotif* of this study.

Based on highly reliable data (information about actual consumption of each irrigation scheme over a period of ten years provided by the CGRAA; regulated water supplied to the CGRAA by the CHE, and available information about annual cropping published by the Regional Government of Aragon), we were able to obtain robust estimates of efficiency levels and potential water deficits in the CGRAA.

An average 85.77% of the total water supplied to the irrigation system from reservoirs is actually used in the irrigation system. This reflects a low level of water losses in transport to the field (14.23%), although canals are open and not piped. Moreover, these losses are even lower in percentage terms during periods of full use of the transport canals (i.e. during the irrigation campaign).

The results reflect average total efficiency of 61% in the CGRAA in the ten years of the study, which entails average field application efficiency of 72%. This represents an impressive leap from efficiency levels of less than 45% three or four decades ago to efficiency levels of more than over 60% today. However, a process of intensive modernisation is currently under way in which ¾ of the area of irrigated land either has been or will be modernised, moving from spray irrigation to drop and sprinkler systems.

Given the 61% level of efficiency achieved and average water allocation of 6.973 m^3/ha over the decade, the net water allocation for plants (i.e. discounting losses) was

4.254 m³/ha, which is insufficient for crops such as maize, rice, industrial crops, potatoes, alfalfa, fruit trees, almonds and vineyards. If total efficiency were raised to 70%, the water allocation would still be insufficient for maize, rice, alfalfa, fruit trees and almonds. This shortage will become more serious if and when irrigated cultivation expands as planned. Specifically, if it is increased to 185,000 hectares, the resulting water deficits of 620 and 410 hm^3 would be so high that they would be impossible to cover with the current water allocations. Even if the area were increased only to 150,000 hectares, the current water allocations would still be insufficient and a deficit of 172 hm^3 would be obtained, even at a total efficiency level of 70%.

In recent years, maize and alfalfa have been the main and most profitable crops in the CGRAA, and also the largest consumer of water, along with rice and fruit trees, and they are significantly more profitable in financial terms than other crops. Although these crops are essential for the agri-food industry and the livestock sector, demand cannot be met by domestic growers, and large quantities are imported from abroad or from other regions of Spain (see Sánchez-Chóliz, 2007 [162]).

Despite the economic importance of these two crops, a shift in cropping patterns to less thirsty crops like barley and wheat has been observed over the last decade. There are a number of reasons for this phenomenon, but perhaps the most important are the insufficiency of the water allocations supplied and the insecurity of supply under existing regulations. Without doubt the decoupling of CAP subsidies in 2006 has significantly influenced these changes. This is because subsidies depend very little on the type of land, and therefore the specific product that is grown and its value. Changes in sales prices (e.g. the falling price of maize in 2008) and rising raw materials and fertilizer prices have also had an impact. Nevertheless, these price and cost issues have had less impact than the problems inherent in chronic water shortages. This explains why the changes gathered pace in the study period, especially in 2005 and 2008, the two years of severe drought.

As explained above, a number of recommendations could be made to help improve this framework of decision. In our opinion, it is first necessary in the short term to bring the modernisation process to an end with the goal of achieving a level of total efficiency of 70% in the next 10 or 15 years. However, transformations should be co-financed; otherwise success looks very difficult.

There can little doubt about the urgency of further measures, because the security of the water supply for current levels irrigation is precarious, as the recent deficit and drought years amply demonstrate. However, new regulations should be limited to what was already planned, as well as the Biscarrués reservoir and Almudévar dam, because the Gallego and Cinca basins are close to their limits, and also because of the environmental and social impacts. However, this additional regulation should not be used to extend the area of irrigated land, which already exceeds 130,000 hectares, but rather to consolidate the current area, improving the security of supply and creating some kind of multi-annual regulation. Only in this way crops such as alfalfa or maize, which are very profitable and economically necessary, will recover their role and survive displacement by cereals such as wheat and barley. Enhancement of the security of irrigation would also favour the expansion of other high value-added crops like fruit trees and vegetables. The future extension of irrigation should therefore be put in place, limiting irrigation to the existing 130,000 hectares. This is the only way to avoid frustrating the expectations of both farmers and society at large. Meanwhile, a policy should seek the withdrawal of irrigated land of poor quality or high salinity, as well as irrigation in areas where high energy costs make it uneconomic. Such withdrawals could be justified by the low returns obtained in the areas affected and by the significant environmental impact.

Undoubtedly these changes need the support of stakeholders and a social consensus to take them forward. This is very important, but we cannot ignore that time also matters in economics. The changes required are urgent and will not wait.

1.3.6. Annex

Table 1.13. **Evolution of efficiency levels in each irrigation community (%)**

Irrigation sub-schemes	**Efficiency**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	***On average***
TARDIENTA	Total	83	76	100	85	79	84	76	*	60	68	*81*
	Field	100	89	100	96	95	96	86	*	83	75	*92*
TORRALBA DE ARAGON	Total	60	63	70	67	96	89	79	76	35	*	*75*
	Field	71	73	80	77	100	100	89	87	48	*	*85*
ALMUDEVAR	Total	39	41	45	47	64	57	53	67	*	81	*55*
	Field	46	48	52	53	78	65	60	76	*	89	*63*
EL TEMPLE	Total	33	32	33	32	55	41	34	33	23	31	*35*
	Field	39	38	38	37	66	47	39	38	31	34	*41*
GURREA DE GALLEGO	Total	32	32	35	36	57	41	39	39	26	37	*38*
	Field	38	37	40	42	69	48	45	45	36	40	*44*
LLANOS DE CAMARERA	Total	86	75	74	65	93	70	54	41	24	32	*61*
	Field	100	89	86	75	100	80	62	47	33	35	*71*
JOAQUÍN COSTA	Total	47	50	51	52	92	67	57	62	35	45	*56*
	Field	56	59	59	60	100	77	64	70	48	49	*64*
COLLARADA 1ª SECCIÓN	Total	75	83	92	83	*	82	81	97	81	*	*83*
	Field	89	97	100	95	*	94	92	100	100	*	*95*
COLLARADA 2ª SECCIÓN	Total	71	73	80	75	83	75	75	83	47	51	*71*
	Field	85	85	91	85	100	87	85	95	65	55	*83*
CARTUJA-SAN JUAN	Total	38	43	46	44	68	50	37	41	32	40	*44*
	Field	46	51	53	50	82	58	42	47	44	44	*51*
LANAJA	Total	38	43	43	41	59	67	41	51	34	46	*46*
	Field	45	51	50	47	71	77	47	58	47	50	*54*
ORILLENA	Total	50	58	54	53	76	59	26	36	38	47	*50*
	Field	60	68	62	60	92	68	29	41	52	51	*58*
SECTOR VIII MONEGROS	Total	50	49	52	51	76	60	50	56	45	83	*57*
	Field	59	57	60	58	92	69	57	64	62	91	*67*
LALUEZA	Total	60	64	77	72	98	75	85	*	*	*	*76*
	Field	72	75	88	82	100	86	96	*	*	*	*86*
ALBERO BAJO	Total	50	57	63	42	72	51	53	43	49	66	*55*
	Field	59	66	73	48	86	59	60	49	67	72	*64*
ALMUNIENTE	Total	56	65	72	62	100	79	64	80	59	73	*71*
	Field	67	76	83	71	100	91	73	91	80	80	*81*
BUÑALES	Total	68	51	63	40	75	51	53	43	49	66	*56*
	Field	81	60	73	45	91	59	60	49	67	72	*66*
CALLEN	Total	57	63	63	59	75	59	55	54	60	60	*60*
	Field	68	73	72	68	90	67	62	61	55	65	*68*
GRAÑEN-FLUMEN	Total	69	75	88	76	98	83	75	74	54	68	*76*
	Field	82	88	100	87	100	95	85	84	75	74	*87*
SANGARREN	Total	89	77	86	76	*	80	*	*	66	78	*79*
	Field	100	90	99	87	*	92	*	*	91	85	*92*
SECTOR VII FLUMEN	Total	72	67	73	67	81	65	59	63	48	61	*66*
	Field	86	78	84	77	98	75	67	71	66	66	*77*
SECTOR X FLUMEN	Total	65	64	68	62	77	67	52	61	43	53	*61*
	Field	77	74	77	71	93	77	59	70	60	58	*72*
SECTOR XI FLUMEN	Total	46	52	47	47	79	63	49	71	56	67	*58*
	Field	55	61	54	54	96	73	55	80	77	73	*68*

Irrigation sub-schemes	**Efficiency**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	***On average***
SODETO-ALBERUELA	Total	73	76	59	55	67	67	54	56	44	54	*60*
	Field	87	88	67	63	80	77	61	64	60	59	*71*
TORRES DE BARBUES	Total	65	71	72	66	*	99	70	93	59	52	*72*
	Field	77	83	82	75	*	100	80	100	81	57	*82*
TRAMACED	Total	82	80	81	72	88	*	82	*	*	*	*81*
	Field	98	94	93	81	100	*	93	*	*	*	*93*
VICIEN	Total	32	35	50	43	76	52	64	56	34	43	*49*
	Field	38	42	58	49	92	60	72	63	46	48	*57*
BARBUES	Total	48	49	48	46	75	54	47	46	29	45	*49*
	Field	58	58	55	53	91	62	53	53	40	49	*57*
CANDASNOS	Total	60	60	70	70	96	67	66	58	50	61	*66*
	Field	71	71	80	79	100	77	75	66	68	67	*75*
LA SABINA	Total	74	72	72	69	88	48	55	66	53	61	*66*
	Field	89	85	83	79	100	56	63	74	72	66	*77*
MONTESNEGROS	Total	61	67	64	66	100	73	65	63	46	58	*66*
	Field	73	79	74	75	100	84	73	72	63	63	*75*
SAN MIGUEL	Total	45	62	59	64	95	64	48	54	44	59	*59*
	Field	54	72	68	72	100	73	55	61	60	64	*68*
ALCONADRE	Total	54	55	55	57	66	73	63	61	49	61	*59*
	Field	65	64	63	65	79	84	72	69	67	67	*70*
LASESA	Total	55	57	59	57	74	75	60	52	*	52	*60*
	Field	65	67	67	64	89	86	68	59	*	57	*69*
LA CAMPAÑA	Total	46	56	44	47	63	80	59	70	49	59	*57*
	Field	55	65	51	54	77	92	67	80	68	65	*67*
LAS ALMÁCIDAS	Total	65	64	73	69	91	64	58	80	53	62	*68*
	Field	78	76	84	78	100	74	65	91	73	67	*79*
MIGUEL SERVET	Total	57	65	73	83	100	65	62	70	54	58	*69*
	Field	68	76	84	95	100	74	70	79	75	64	*78*
SAN PEDRO	Total	63	55	61	48	65	56	66	56	38	46	*55*
	Field	75	64	70	54	79	65	74	63	53	51	*65*
SANTA CRUZ	Total	50	49	53	52	84	55	48	55	38	47	*53*
	Field	59	57	60	60	100	63	55	63	53	51	*62*
VAL DE ALFERCHE	Total	68	72	83	75	77	89	73	89	62	73	*76*
	Field	81	84	95	85	93	100	82	100	85	80	*89*
A-19-20	Total	59	56	59	58	77	82	62	74	56	68	*65*
	Field	71	66	68	66	93	94	71	84	77	74	*76*
LA CORONA	Total	98	87	100	98	87	74	68	74	60	86	*83*
	Field	100	100	100	100	100	85	77	84	83	94	*93*

**These years are not included due to the lack of data.*

Source: Own work based on CGRAA data.

1.4. Appendix A: Supplementary Tables to Chapter 1

Table A1. **Volume of water consumed in the CGRAA 2001-2010 (Thousands of m^3)**

	2001			**2002**			**2003**			**2004**			**2005**		
Irrigation sub-schemes	**Irrigation**	**Urban**	**Industrial**	**Irrigation**	**Urban**	**Industrial**	**Irrigation**	**Urban**	**Industrial**	**Irrigation**	**Urban**	**Industrial**	**Irrigation**	**Urban**	**Industrial**
PUIPULLIN	698	0	0	482	0	0	511	0	0	537	0	0	506	0	0
TOTAL GÁLLEGO AREA	**698**	**0**	**0**	**482**	**0**	**0**	**511**	**0**	**0**	**537**	**0**	**0**	**506**	**0**	**0**
TARDIENTA	6241	211	6	5552	215	7	5003	191	5	5915	176	7	4455	159	10
ALCALA DE GURREA	1646	0	0	1349	0	0	1112	0	0	1019	0	0	845	0	0
FRULA	1026	0	0	697	0	0	492	0	0	710	0	0	610	0	0
MONTE-FRULA	2765	0	0	1909	0	0	2668	0	0	3038	0	0	1853	0	0
TORRALBA DE ARAGON	7297	23	0	6129	24	0	6117	18	0	6366	30	1	3341	24	5
VALFONDA	9677	41	16	7881	43	39	7547	27	23	8509	29	32	4669	37	36
ALMUDEVAR	34529	456	110	29541	423	50	29803	479	48	27910	448	54	14874	461	118
EL TEMPLE	15906	0	0	14532	121	0	15901	74	0	16021	0	0	6776	0	0
GURREA DE GALLEGO	24666	130	75	21684	143	60	22417	226	195	20989	299	171	9651	372	162
JOAQUÍN COSTA	11879	801	82	10709	821	180	10885	1027	205	10520	1165	193	4774	873	630
LLANOS DE CAMARERA	6457	180	0	7131	180	0	7534	180	7	8395	175	15	4837	215	1
SASO SAN MATEO DE GALLEGO	4364	611	0	3600	626	0	3820	640	0	4070	635	0	1104	931	0
TOTAL MONEGROS 1º-2º AREA	**126453**	**2453**	**289**	**110714**	**2596**	**336**	**113299**	**2862**	**483**	**113462**	**2957**	**473**	**57789**	**3072**	**962**
COLLARADA 1ª SECCIÓN	15255	312	120	12052	315	108	11901	297	112	13474	361	69	8572	365	113
COLLARADA 2ª SECCIÓN	16919	15	7	16119	21	11	15381	43	21	16589	44	15	10139	16	30
CARTUJA-SAN JUAN	32041	207	5	27226	168	7	27192	166	7	29091	168	9	13016	168	8
LANAJA	40534	120	38	32405	110	36	34996	130	42	36315	120	47	16657	120	54
SAT 5007	2214	0	0	1966	0	0	2017	0	0	2272	0	0	1200	0	0
ORILLENA	15176	43	1	12547	32	0	14099	39	0	14793	26	1	7105	30	12
SECTOR VIII MONEGROS	17212	48	17	16090	48	16	16025	51	20	16521	56	32	7573	56	45
LALUEZA	19304	0	0	16568	0	0	14140	0	0	15711	0	0	7953	15	0
TOTAL MONEGROS 2º-3º AREA	**158655**	**745**	**188**	**134973**	**694**	**178**	**135751**	**726**	**202**	**144766**	**775**	**173**	**72215**	**770**	**262**
ALBERO BAJO	1384	0	0	1237	0	0	1129	0	0	1700	0	0	950	0	0
ALMUNIENTE	9349	56	14	7144	103	18	7124	59	21	8323	83	39	3681	100	59
BARBUES	12177	14	11	10816	16	17	12135	15	13	13140	14	30	5429	14	42
BUÑALES	882	0	0	1084	0	0	872	0	0	1464	0	0	641	0	0
CALLEN	8996	11	5	7556	7	0	8099	10	7	8603	13	1	4859	15	8
FRAELLA	339	0	0	301	0	0	304	0	0	320	0	0	142	0	0
GRAÑEN-FLUMEN	14006	356	40	11872	479	11	10875	417	29	12540	18	11	7030	0	44

PIRACES	1285	0	0	1123	0	1	1194	0	0	1293	0	0	941	0	2
SANGARREN	8349	81	5	7651	98	21	8013	92	22	9570	142	20	6254	182	66
SECTOR VII FLUMEN	19247	18	44	19205	18	7	18502	20	52	20446	12	14	11987	0	41
SECTOR X FLUMEN	17868	19	13	17268	6	25	17312	2	8	19150	0	21	10989	0	12
SECTOR XI FLUMEN	30732	116	5	26420	194	18	31131	191	7	31470	180	4	13185	280	3
SODETO-ALBERUELA	10645	13	18	9389	0	11	12850	0	9	14523	0	17	8584	34	21
TORRES DE BARBUES	6360	26	17	5583	29	10	5749	23	16	6419	24	11	2546	31	17
TRAMACED	4539	2		4205	0	2	4609	0	0	5242	2	0	3171	0	1
VICIEN	3835	22	1	3084	23	2	2636	25	0	3142	32	3	1361		1
TOTAL FLUMEN AREA	**149993**	**734**	**173**	**133938**	**973**	**143**	**142534**	**854**	**184**	**157345**	**520**	**171**	**81750**	**656**	**317**
CANDASNOS	29930	42	0	31363	0	0	30148	0	0	30876	187	4	16898	418	1
LA SABINA	8510	0	0	8575	29	0	9157	27	0	9806	28	0	5936	10	10
MONTESNEGROS	27980	948	0	26296	0	0	27855	0	0	27130	0	0	14160		0
SAN MIGUEL	37047	0	0	27222	1047	0	29710	998	61	27746	1015	159	14673	1069	121
TOTAL MONEGROS II Y TRAMO IV AREA	**103467**	**990**	**0**	**93456**	**1076**	**0**	**96870**	**1025**	**61**	**95558**	**1230**	**163**	**51667**	**1497**	**132**
TOTAL MONEGROS AREA	**539266**	**4922**	**650**	**473563**	**5339**	**657**	**488965**	**5467**	**930**	**511668**	**5482**	**980**	**263927**	**5995**	**1673**
ALCONADRE	19023	144	0	18850	73	0	19679	112	0	19799	135	0	11858	137	56
LASESA	74898	73	30	69207	75	00	71987	86	0	75398	73	0	41380	78	50
PERTUSA-SECTOR XXVII-XXXIII	768	22	0	553	23	1	638	30	3	585	28	0	391	26	4
TOTAL PERTUSA AREA	**94689**	**239**	**30**	**88610**	**171**	**1**	**92304**	**228**	**3**	**95782**	**236**	**0**	**53629**	**241**	**110**
EL GRADO	279	143	0	233	106		215	91	0	189	92	0	252	94	3
LA CAMPAÑA-CONCHEL	34355	251	2150	28125	111	2667	30969	347	2108	32367	341	2330	18394	318	1978
LAS ALMÁCIDAS	25592	24	2	25004	22	0	23848	25	0	26500	27	0	15870	50	120
MIGUEL SERVET	15267	156	0	14622	148	0	13419	153	0	12097	149	0	7293	122	2
Nº 1 CANAL DEL CINCA	10476	1520	1720	9794	1551	1479	9884	1713	1467	8913	1502	1560	8716	1772	1448
SAN JUAN	6338	177	0	5828	213	1	6535	199	1	6775	174	0	4413	217	6
SAN PEDRO	27565	162	8	28113	130	2	27943	154	0	29753	156	0	17203	169	10
SANTA CRUZ	31359	465	17	30706	413	112	30922	420	85	32540	485	16	15472	483	48
VAL DE ALFERCHE	28022	7	10	25035	6	7	23469	4	0	27305	15	0	22601	21	67
TOTAL TRAMO 1º CINCA AREA	**179253**	**2905**	**3907**	**167460**	**2700**	**4268**	**167204**	**3106**	**3661**	**176439**	**2941**	**3906**	**110214**	**3246**	**3682**
A-19 Y A-20	25985	137	0	25035	151	70	26574	239	0	27223	271	0	18880	53	20
LA CORONA-SECTOR 36	8196	60	0	8709	48	0	7851	222	0	8693	763	0	7863	750	25
TOTAL TRAMO 3º CINCA AREA	**34181**	**197**	**0**	**33744**	**199**	**70**	**34425**	**461**	**0**	**35916**	**1034**	**0**	**26743**	**803**	**45**
TOTAL CINCA AREA	**308123**	**3341**	**3937**	**289814**	**3070**	**4339**	**293933**	**3795**	**3664**	**308137**	**4211**	**3906**	**190586**	**4290**	**3837**
TOTAL CGRAA	**848587**	**8328**	**4587**	**764434**	**8509**	**5011**	**783800**	**9359**	**4594**	**821068**	**9825**	**4886**	**455177**	**10431**	**5610**
Others	1198	65	0	1057	100	15	902	97	0	1263	132	0	664	146	100

	2006			2007			2008			2009			2010		
Irrigation sub-schemes	**Irrigation**	**Urban**	**Industrial**	**Irrigation**	**Urban**	**Industrial**	**Irrigation**	**Urban**	**Industrial**	**Irrigation**	**Urban**	**Industrial**	**Irrigation**	**Urban**	**Industrial**
PUIPULLIN	505	0	0	465	0	0	281	0	0	231	0	0	264	0	0
TOTAL GÁLLEGO AREA	**505**	**0**	**0**	**0**	**0**	**0**	**281**	**0**	**0**	**231**	**0**	**0**	**264**	**0**	**0**
TARDIENTA	4467	226	14	4919	178	12	1020	238	17	4404	189	12	4581	171	20
ALCALA DE GURREA	870	0	0	845	0	0	963	0	0	1042	185	4	1027	190	3
MONTE-FRULA	2191	0	0	2002	0	0	0	0	0	0	0	0	0	0	0
TORRALBA DE ARAGON	4495	25	4	4584	25	7	4125	27	3	0	14	0	0	0	0
VALFONDA	7117	53	48	7213	24	42	4889	36	36	1451	29	0	0	0	0
SANTA ANA	0	0	0	0	0	0	0	0	0	13486	0	46	13698	48	41
ALMUDEVAR	20106	474	111	20576	427	82	9218	369	61	3282	383	39	9545	378	3
EL TEMPLE	12068	0	0	14618	0	101	12461	0	0	15894	0	0	14623	0	0
GURREA DE GALLEGO	14182	312	151	16533	293	141	15639	276	103	20310	355	84	18500	279	89
HUERTA ALTA DE GURREA DE GÁLLEGO	15	0	0	0	0	0	0		0	0	0	0	0	0	0
JOAQUÍN COSTA	6888	890	635	7530	886	490	6605	852	479	9918	827	0	9620	848	489
LLANOS DE CAMARERA	7095	268	3	9201	291	0	12113	273	0	17200	323	0	16425	238	0
SASO SAN MATEO DE GALLEGO	7095	641	10	3460	738	0	3031	963	0	3785	1058	0	2550	980	0
TOTAL MONEGROS 1º-2º AREA	**86589**	**2889**	**976**	**0**	**0**	**0**	**70064**	**3034**	**699**	**90772**	**3363**	**185**	**90569**	**3132**	**645**
COLLARADA 1ª SECCIÓN	10682	374	139	10959	366	195	9207	399	192	9023	447	180	7880	431	184
COLLARADA 2ª SECCIÓN	11515	14	39	12682	87	32	10027	85	34	14668	56	32	15805	68	17
CARTUJA-SAN JUAN	19563	243	11	26705		12	22886	249	13	26830	247	8	26483	310	11
LANAJA	23066	110	79	28226	115	80	23511	152	88	29762	156	115	28212	156	90
ORILLENA	10878	39	15	13642	40	5	11105	23	4	14252	29	4	14505	25	2
SECTOR VIII MONEGROS	11279	50	42	13683	62	43	10948	66	43	12159	51	56	8970	40	57
LALUEZA	11998	30	25	11290	0	21	2984	10	25	6060	0	25	8935	40	0
TOTAL MONEGROS 2º-3º AREA	**98981**	**860**	**350**	**0**	**0**	**0**	**90668**	**984**	**399**	**112754**	**986**	**420**	**110790**	**1070**	**361**
ALBERO BAJO	1135	0	0	1402	0	0	1169	0	0	1575	0	0	1388	0	0
ALMUNIENTE	5518	61	58	6823	48	23	5516	27	50	6623	47		6509	42	29
BARBUES	9426	18	46	11414	18	49	9416	13	56	11537	15	86	12620	13	27
BUÑALES	934	0	0	1254	0	0	1204	10	0	1115	0	0	1084	0	0
CALLEN	6452	13	9	8531	15	52	7099	0	94	8702	12	114	7522	10	48
FRAELLA	234	0	0	305	0	0	231	0	0	204	0	0	188	0	0
GRAÑEN-FLUMEN	9467	0	30	10269	0	19	9927	0	47	12211	0	39	12577	0	48
PIRACES	1124	0	1	500	0	1	0	0	0	0	0	0	0	0	0
SANGARREN	7234	152	34	7162	164	18	6034	171	33	7459	92	26	8283	73	10
SECTOR VII FLUMEN	17074	4	35	18992	0	31	15978	0	64	19107	0	7	18979	0	3

SECTOR X FLUMEN	14144	1	22	16842	4	8	14449	0	13	19256	0	10	19602	0	8
SECTOR XI FLUMEN	18400	280	2	25958	158	2	16199	144	1	19323	231	0	20148	74	0
SODETO-ALBERUELA	9814	43	38	12687	40	43	10422	5	29	12610	2	26	12535	3	28
TORRES DE BARBUES	3813	30	24	5103	35	20	3499	32	16	5362	39	9	6633	39	9
TRAMACED	3690	0	0	4074	0	0	965	1	0	175	0	0	86	0	0
VICIEN	1885	27	1	2611	20	1	1938	20	129	3325	0	0	3383	0	0
TOTAL FLUMEN AREA	**110344**	**629**	**300**	**0**	**0**	**0**	**104046**	**423**	**532**	**128584**	**438**	**317**	**131537**	**254**	**210**
CANDASNOS	28138	431	0	36689	347	0	29945	349	0	36249	328	0	37626	363	40
LA SABINA	11278	32	0	13876	6	35	10884	22	0	12614	24	0	13556	6	7
MONTESNEGROS	24010	0	40	26958	0	150	22730	0	90	28385	2196	0	28713	2202	105
SAN MIGUEL	25533	948	128	31958	974	277	27228	855	183	32478	837	284	30224	787	370
TOTAL MONEGROS II Y TRAMO IV AREA	**88959**	**1411**	**168**	**0**	**0**	**0**	**90787**	**1226**	**273**	**109726**	**3385**	**284**	**110119**	**3358**	**522**
TOTAL MONEGROS AREA	**385378**	**5789**	**1794**	**0**	**0**	**0**	**355846**	**5667**	**1903**	**442067**	**8172**	**1206**	**443279**	**7814**	**1738**
ALCONADRE	15887	150	6	18595	136	6	14817	115	6	17760	89	0	17473	81	4
LASESA	59763	79	100	81454	96	200	64555	71	0	7677	54	0	74621	55	0
PERTUSA-SECTOR XXVII-XXXIII	382	29	9	377	40	17	246	44	5	330	43	0	280	43	18
TOTAL PERTUSA AREA	**76032**	**258**	**115**	**0**	**0**	**0**	**79618**	**230**	**11**	**25767**	**186**	**0**	**92374**	**179**	**22**
EL GRADO	269	89	8	209	83	3	193	65	2	191	70	0	98	84	0
LA CAMPAÑA-CONCHEL	21219	322	2589	24060	279	2680	22060	256	2100	26050	269	0	27600	278	1540
LAS ALMÁCIDAS	20713	33	50	24625	27	4	17858	19	0	24219	27	0	26681	25	0
MIGUEL SERVET	10899	100	16	14061	95	0	10969	60	0	13536	110	0	15183	100	0
Nº 1 CANAL DEL CINCA	8901	1642	1486	8299	1797	1301	7531	1542	1310	7692	1555	0	7116	1537	1469
SAN JUAN	5236	228	4	6505	200	9	5462	193	2	4504	227	0	5235	262	10
SAN PEDRO	25081	178	24	30875	121	18	21815	110	8	33079	114	0	39291	87	0
SANTA CRUZ	22232	615	123	28832	459	103	24518	458	66	34111	496	0	35480	498	246
VAL DE ALFERCHE	25437	17	29	27897	27	11	22458	12	0	29730	55	0	30408	55	0
TOTAL TRAMO 1º CINCA AREA	**139987**	**3224**	**4329**	**0**	**0**	**0**	**132864**	**2715**	**3488**	**173112**	**2923**	**0**	**187092**	**2926**	**3265**
A-19 Y A-20	23335	244	25	26582	187	51	20086	306	15	24062	303	0	23470	260	0
LA CORONA-SECTOR 36	10113	760	25	13057	739	0	12370	658	0	14284	1328	0	12745	708	0
TOTAL TRAMO 3º CINCA AREA	**33448**	**1004**	**50**	**0**	**0**	**0**	**32456**	**964**	**15**	**38346**	**1631**	**0**	**36215**	**968**	**0**
TOTAL CINCA AREA	**249467**	**4486**	**4494**	**0**	**0**	**0**	**244938**	**3909**	**3514**	**237225**	**4740**	**0**	**315681**	**4073**	**3287**
TOTAL CGRAA	**634987**	**10432**	**6288**	**0**	**0**	**0**	**600784**	**9606**	**5417**	**681732**	**12977**	**1206**	**758960**	**11887**	**5025**
Others	142	157	0	0	0	0	0	30	0	2440	65	0	0	0	0

Source: CGRAA.

Table A2. **Total hectares**

Irrigation communities	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
PUIPULLIN	105	105	105	105	105	105	105	105	150	105
TOTAL GÁLLEGO AREA	**105**	**105**	**105**	**105**	**105**	**105**	**105**	**105**	**150**	**105**
TARDIENTA	1474	1489	1472	1470	1453	1453	1456	1456	1450	1449
ALCALA DE GURREA	299	299	299	299	299	299	299	299	299	299
MONTE-FRULA	558	558	558	558	558	558	558	558	558	0
TORRALBA DE ARAGON	1027	1027	1023	1024	1024	1024	1024	1024	1192	2627
VALFONDA	885	885	892	892	892	892	892	892	892	0
ALMUDEVAR	3771	3685	3671	3675	3674	3674	3674	3656	3738	3813
EL TEMPLE	1472	1472	1472	1472	1472	1472	1472	1472	1472	1472
GURREA DE GALLEGO	2187	2188	2179	2184	2184	2188	2188	2188	2161	2200
HUERTA ALTA DE GURREA DE GÁLLEGO	40	40	40	40	40	40	40	40	40	0
JOAQUÍN COSTA	1143	1143	1145	1145	1145	1145	1050	1018	1014	1014
LLANOS DE CAMARERA	1143	1143	1143	1143	1163	1163	1163	1161	1161	1161
SASO SAN MATEO DE GALLEGO	458	458	458	458	458	458	458	458	458	458
TOTAL MONEGROS 1º-2º AREA	**14457**	**14387**	**14352**	**14359**	**14362**	**14366**	**14274**	**14222**	**14435**	**14493**
COLLARADA 1ª SECCIÓN	2918	2916	2909	2925	2925	2925	2925	2928	2759	2759
COLLARADA 2ª SECCIÓN	2944	2956	2958	2958	2958	2945	2928	2945	3146	3146
CARTUJA-SAN JUAN	2921	2921	2921	2921	2921	2921	2945	2771	2771	2771
LANAJA	3731	3731	3731	3735	3735	3735	3738	3738	3738	3738
SAT 5007	1644	1644	1644	1644	1644	1644	2771	0	0	0
ORILLENA	1971	1971	1971	1971	1971	1971	1971	1971	1971	1971
SECTOR VIII MONEGROS	2090	2171	2188	2175	2181	2198	2197	2199	2199	2366
LALUEZA	2805	2804	2805	2819	2819	2819	2819	2819	2819	2819
TOTAL MONEGROS 2º-3º AREA	**21024**	**21114**	**21127**	**21148**	**21154**	**21158**	**22295**	**19371**	**19403**	**19571**
ALBERO BAJO	423	423	423	426	426	426	426	426	420	420
ALMUNIENTE	1259	1262	1262	1262	1262	1261	1261	1261	1261	1261
BARBUES	1434	1434	1434	1436	1436	1436	1436	1431	1431	1549
BUÑALES	150	150	150	150	150	150	150	150	155	155
CALLEN	1468	1468	1468	1468	1468	1468	1468	1468	1468	1468
FRAELLA	81	81	81	81	81	81	81	81	0	0
GRAÑEN-FLUMEN	2124	2124	2124	2124	2124	2118	2121	2122	2123	2123
PIRACES	365	365	365	365	365	365	365	365	427	427
SANGARREN	1844	1842	1963	1961	1961	1961	1968	1968	1968	1968
SECTOR VII FLUMEN	3218	3195	3218	3237	3235	3244	3235	3342	3334	3354
SECTOR X FLUMEN	2776	2850	2848	2848	2848	2848	2847	2847	2847	2853

SECTOR XI FLUMEN	3409	3408	3395	3386	3397	3409	3397	3393	3469	3469
SODETO-ALBERUELA	1859	1855	1852	1946	1946	1945	1944	1944	1948	1946
TORRES DE BARBUES	826	826	826	826	826	826	826	826	826	722
TRAMACED	932	932	932	932	932	932	932	932	1013	1013
VICIEN	314	314	376	376	376	314	317	310	321	321
TOTAL FLUMEN AREA	**22482**	**22529**	**22719**	**22826**	**22833**	**22785**	**22776**	**22867**	**23012**	**23049**
CANDASNOS	3802	3909	4186	4186	4344	4344	4344	4344	4344	4344
LA SABINA	1553	1514	1514	1514	1666	1666	2084	2084	2084	2084
MONTESNEGROS	3600	3600	3475	3475	3475	3475	3475	3509	3509	3509
SAN MIGUEL	3600	3600	3600	3600	3600	3600	3815	3815	3815	3815
TOTAL MONEGROS II Y TRAMO IV AREA	**12555**	**12623**	**12775**	**12775**	**13085**	**13085**	**13718**	**13752**	**13752**	**13752**
TOTAL MONEGROS AREA	**70623**	**70759**	**71078**	**71214**	**71539**	**71498**	**73168**	**70317**	**70752**	**70970**
ALCONADRE	3180	3218	3223	3223	3223	3224	3224	3224	3224	3227
LASESA	9786	9786	9786	9786	9786	9786	9786	9786	9786	9786
PERTUSA-SECTOR XXVII-XXXIII	185	185	186	186	186	186	186	186	186	186
TOTAL PERTUSA AREA	**13150**	**13189**	**13195**	**13195**	**13195**	**13196**	**13196**	**13196**	**13196**	**13198**
CONCHEL	0	0	0	0	0	0	0	0	0	0
EL GRADO	200	200	200	200	200	200	200	200	200	200
LA CAMPAÑA-CONCHEL	4960	4950	4950	4950	4942	4942	5257	5277	5277	5277
LAS ALMÁCIDAS	4491	4515	4515	4515	4515	4515	4515	4615	4615	4615
MIGUEL SERVET	1964	2223	2223	2223	2223	2223	2330	2330	2330	2332
Nº 1 CANAL DEL CINCA	3990	4046	4060	4476	4463	4468	4528	4520	4483	4411
SAN JUAN	1432	1474	1522	1709	1580	1488	1695	1695	1695	1695
SAN PEDRO	4850	4850	4850	4850	4850	4850	5231	5334	5334	5334
SANTA CRUZ	4016	4016	4016	4016	4016	4016	4173	4173	4173	4173
VAL DE ALFERCHE	6566	6794	6779	6804	6804	6896	7005	7030	7030	7030
TOTAL TRAMO 1º CINCA	32469	33068	33114	33742	33592	33597	34935	35173	35137	35067
A-19 Y A-20	4254	4214	4179	4177	5095	5201	5200	5198	5198	5133
LA CORONA-SECTOR 36	1875	1891	1891	1941	2127	2298	2477	2656	2842	2842
TOTAL TRAMO 3º CINCA AREA	**6129**	**6105**	**6070**	**6118**	**7222**	**7499**	**7676**	**7854**	**8040**	**7975**
SECTOR XXXIV (A-19-20)	253	424	429	527	0	0	0	0	0	0
BUÑALES	100	100	100	0	0	0	0	0	0	0
TABERNAS DE ISUELA	325	325	325	0	0	0	0	0	0	0
TOTAL CINCA PROVISIONAL AREA	**678**	**849**	**854**	**527**	**0**	**0**	**0**	**0**	**0**	**0**
TOTAL CINCA AREA	**52426**	**53210**	**53233**	**53582**	**54008**	**54291**	**55807**	**56223**	**56372**	**56240**
TOTAL CGRAA	**123049**	**123969**	**124311**	**124795**	**125547**	**125790**	**128974**	**126539**	**127124**	**127210**

Source: Own work based on CGRAA data.

Table A3. **Hectares with high irrigation priority**

Irrigation sub-schemes	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
PUIPULLIN	105	105	105	105	105	105	105	105	105	105
TOTAL GÁLLEGO AREA	**105**	**105**	**105**	**105**	**105**	**105**	**105**	**105**	**105**	**105**
TARDIENTA	1414	1429	1413	1410	1394	1394	1392	1392	1386	1385
ALCALA DE GURREA	269	269	269	269	269	269	269	269	269	269
MONTE-FRULA	504	504	504	504	504	504	504	504	504	0
TORRALBA DE ARAGON	960	960	958	958	958	958	958	958	504	2507
VALFONDA	885	885	892	892	892	892	892	892	1126	0
ALMUDEVAR	3603	3518	3507	3503	3502	3502	3506	3513	3595	3548
EL TEMPLE	1472	1472	1472	1472	1472	1472	1472	1472	1472	1472
GURREA DE GALLEGO	2187	2188	2179	2184	2184	2188	2188	2188	2161	2200
HUERTA ALTA DE GURREA DE GÁLLEGO	40	40	40	40	40	40	40	40	40	0
JOAQUÍN COSTA	1143	1143	1145	1145	1145	1145	1050	1018	1014	1014
LLANOS DE CAMARERA	1143	1143	1143	1143	1163	1163	1163	1161	1161	1161
SASO SAN MATEO DE GALLEGO	388	388	388	388	388	388	388	388	388	388
TOTAL ZONA MONEGROS 1º-2º	14008	13938	13910	13908	13911	13914	13822	13795	13619	13943
COLLARADA 1ª SECCIÓN	2699	2696	2685	2695	2695	2695	2695	2695	2527	2527
COLLARADA 2ª SECCIÓN	2660	2673	2671	2671	2671	2669	2669	2669	2669	2669
CARTUJA-SAN JUAN	2921	2921	2921	2921	2921	2921	2771	2771	2771	2771
LANAJA	3639	3639	3639	3639	3639	3639	3639	3639	3639	3639
SAT 5007	1639	1639	1639	1639	1639	0	0	0	0	0
ORILLENA	1819	1819	1819	1819	1819	1819	1819	1819	1819	1819
SECTOR VIII MONEGROS	2002	1997	2016	2002	2008	2028	2029	2028	2028	2195
LALUEZA	2758	2758	2758	2742	2742	2742	2742	2742	2742	2742
TOTAL MONEGROS 2º-3ºAREA	**20137**	**20142**	**20148**	**20128**	**20134**	**18513**	**18364**	**18363**	**18194**	**18361**
ALBERO BAJO	389	389	389	389	389	389	389	389	383	383
ALMUNIENTE	1149	1152	1152	1152	1152	1151	1151	1151	1151	1151
BARBUES	1289	1289	1289	1289	1289	1289	1289	1284	1284	1402
BUÑALES	150	150	150	150	150	150	150	150	155	155
CALLEN	1290	1290	1290	1290	1290	1290	1290	1290	1290	1290
FRAELLA	81	81	81	81	81	81	81	81	0	0
GRAÑEN-FLUMEN	2103	2103	2103	2103	2103	2097	2098	2098	2100	2100
PIRACES	354	354	354	354	354	354	354	354	354	354
SANGARREN	1844	1842	1963	1961	1961	1961	1961	1961	1961	1961
SECTOR VII FLUMEN	3139	3133	3137	3137	3140	3149	3139	3128	3123	3115
SECTOR X FLUMEN	2737	2737	2736	2736	2736	2736	2739	2739	2739	2744

SECTOR XI FLUMEN	3349	3348	3336	3327	3337	3350	3338	3334	3410	3410
SODETO-ALBERUELA	1828	1828	1827	1895	1895	1894	1893	1893	1897	1897
TORRES DE BARBUES	824	824	824	824	824	824	824	824	824	722
TRAMACED	925	925	925	925	925	925	925	925	1006	1006
VICIEN	310	310	372	372	372	310	310	310	318	318
TOTAL FLUMEN AREA	**21761**	**21755**	**21928**	**21985**	**21998**	**21950**	**21932**	**21913**	**21994**	**22008**
CANDASNOS	3802	3909	4186	4186	4344	4344	4344	4344	4344	4344
LA SABINA	1514	1514	1514	1514	1666	1666	2084	2084	2084	2084
MONTESNEGROS	0	0	0	3475	3475	3475	3475	3509	3509	3509
SAN MIGUEL	3600	3600	3600	3600	3600	3600	3815	3815	3815	3815
TOTAL MONEGROS II Y TRAMO IV AREA	**5114**	**5114**	**5114**	**8589**	**8741**	**8741**	**9374**	**9408**	**9408**	**9408**
TOTAL MONEGROS AREA	**64927**	**64964**	**65391**	**68902**	**69233**	**67567**	**67942**	**67927**	**67664**	**68169**
ALCONADRE	3176	3218	3218	3218	3218	3219	3219	3219	3219	3222
LASESA	9786	9786	9786	9786	9786	9786	9786	9786	9786	9786
PERTUSA-SECTOR XXVII-XXXIII	185	185	186	186	186	186	186	186	186	186
TOTAL PERTUSA AREA	**13147**	**13189**	**13190**	**13190**	**13190**	**13191**	**13191**	**13191**	**13191**	**13193**
EL GRADO	200	200	200	200	200	200	200	200	200	200
LA CAMPAÑA-CONCHEL	4895	4893	4893	4893	4893	4893	5038	5038	5038	5038
LAS ALMÁCIDAS	4491	4515	4515	4515	4515	4515	4515	4615	4615	4615
MIGUEL SERVET	1964	2197	2197	2197	2197	2197	2197	2197	2197	2199
Nº 1 CANAL DEL CINCA	3512	3568	3482	3263	3254	3258	3254	3223	3197	3144
SAN JUAN	1432	1353	1449	1448	1448	1358	1362	1362	1362	1362
SAN PEDRO	4700	4700	4700	4700	4700	4700	5081	5170	5170	5170
SANTA CRUZ	3990	3990	3990	3990	3990	3990	4142	4142	4142	4142
VAL DE ALFERCHE	6566	6607	6591	6591	6591	6681	6740	6740	6740	6740
TOTAL TRAMO 1º CINCA AREA	**31750**	**32021**	**32016**	**31796**	**31786**	**31790**	**32528**	**32686**	**32660**	**32609**
A-19 Y A-20	4235	4194	4159	4157	5075	5148	5147	5147	5147	5082
LA CORONA-SECTOR 36	1875	1891	1891	1941	2127	2298	2477	2656	2842	2842
TOTAL TRAMO 3º CINCA AREA	**6110**	**6085**	**6050**	**6098**	**7202**	**7447**	**7624**	**7803**	**7989**	**7924**
TOTAL CINCA AREA	**51006**	**51295**	**51256**	**51084**	**52177**	**52428**	**53343**	**53680**	**53839**	**53726**
TOTAL CGRAA	**115933**	**116259**	**116647**	**119985**	**121410**	**119995**	**121284**	**121606**	**121503**	**121896**

Source: Own work based on CGRAA data.

Table A4. **Current status of modernization in the CGRAA**

Situation with modernization		**Situation with agreement**		**Situation: Old modernization (sprinkler)**		**Situation: Some works (dam or gully catchment)**		**Situation: Without modernization**	
Irrigation sub-schemes	**Ha 2010**	**Irrigation sub-schemes**	**Ha 2010**	**Irrigation sub-schemes**	**Ha 2010**	**Irrigation sub-schemes**	**Ha 2010**	**Irrigation sub-schemes**	**Ha 2010**
Almudévar	3813	A-19 y A20	5133	Alconadre	3227	El Temple	1472	Almuniente	1261
Collarada 2º sección	3146	Albero Bajo	420	Candasnos	4344	Gurrea de Gállego	2200	Buñales	155
La Campaña	5277	Callén	1468	La Corona	2842	Joaquín Costa	1014	Collarada 1º sección	2759
Lalueza	2819	Cartuja - San Juan	2771	La Sabina	2084	Llanos de Camarera	1161	Grañén-Flumen*	2123
Miguel Servet	2332	Las Almácidas	4615	Lasesa	9786	Saso	458	El Grado	200
Piraces	427	Nº 1 Canal del Cinca	4411	Montesnegros	3509			Alcalá de Gurrea	299
San Juan	1695	Sangarrén	1968	San Miguel	3815			Lanaja*	3738
San Pedro	5334	Torres de Barbués	722					Orillena	1971
Sector VII Flumen	3354	Barbués	1549					Pertusa	186
Sector XI	3469							Santa Cruz*	4173
Sodeto - Alberuela	1946							Sector X del Flumen	2853
Tramaced	1013							Tardienta	1449
Val de Alferche	7030							Vicién	321
Sector VIII Monegros	2366							Torralba de Aragón	2627
								Puipullín	105
TOTAL	**44022**	**TOTAL**	**23057**	**TOTAL**	**29606**	**TOTAL**	**6304**	**TOTAL**	**24220**

**Irrigation plans for sub-schemes currently under negotiation.*

Source: CGRAA.

Table A5. **Cropping patterns in the Monegros area (Ha with high irrigation priority)**

CROPS	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Wheat	945	2919	2374	2513	2406	3386	4188	5756	3538	5050
Barley	3365	4931	5379	5890	7498	11607	12577	17419	13087	15286
Oats	17	50	64	149	51	50	43	186	79	90
Maize	25467	21218	21921	21348	11899	11147	13135	12127	14334	13181
Rice	3324	2843	2920	3562	2461	2386	3175	2371	3065	3877
Sorghum	225	194	159	206	131	2790	1294	133	324	774
Peas	185	362	208	328	886	761	391	942	809	947
Other Legumes	103	65	47	86	64	17	8	11	42	71
Potatoes	73	78	52	28	100	50	0	0	0	0
Sunflower	4324	2171	2757	1709	1137	768	289	891	1005	523
Colza	311	112	55	239	39	22	72	13	28	22
Other industrial crops	272	71	45	30	33	9	20	3	46	1
Tomatoes	22	19	23	45	36	2	29	7	8	12
Onions	0	0	0	21	31	45	0	0	0	0
Other vegetables	224	270	220	167	100	247	171	122	123	129
Alfalfa	18543	19511	20831	20628	19456	18732	16816	13495	15476	16056
Fodder vetches	25	33	22	19	10	142	100	35	136	376
Other fodder	917	900	1010	1241	1075	2522	2813	2252	2640	2949
Other herbaceous	120	120	121	346	203	38	45	81	49	57
Apple trees	59	49	70	71	69	341	48	72	68	67
Pear trees	19	15	19	19	18	2	9	16	18	17
Cherry trees	5	4	6	6	6	2	3	11	13	17
Plum trees	6	5	6	8	9	6	3	3	4	4
Apricot trees	1	0	25	25	19	10	5	8	8	8
Peach trees	78	78	128	112	124	98	35	158	148	156
Almond trees	82	85	95	125	130	47	110	164	184	200
Other fruit trees	35	38	61	64	67	53	722	90	93	98
Olives	156	354	361	366	332	106	241	335	329	324
Grapes	11	10	14	13	15	290	12	7	8	9
No crop	0	0	0	0	0	3298	1660	797	2708	5071
Mandatory withdrawal	3140	4098	3110	2762	7320	1312	1537	697	25	24
Voluntary withdrawal	1400	2821	1171	1209	7683	2943	3216	5767	4805	253
Black poplar and other forest	62	59	34	36	30	17	82	46	25	36
Unassigned	0	0	0	0	0	3	13	5	0	0
Fallow crop	0	2	1	7	20	32	9	71	54	312
Double crops	0	0	0	0	0	686	1278	0	0	5
Dehydrated crops	747	813	1275	1320	1509	1020	1161	1202	1598	1049
TOTAL	**64262**	**64299**	**64594**	**64630**	**64961**	**64934**	**65308**	**65294**	**64878**	**67053**

Source: Own work based on DGA (2011a [57]).

Table A6. **Cropping patterns in the Cinca area (Ha with high irrigation priority)**

CROPS	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Wheat	1544	2135	1968	3207	1740	1933	3158	3719	1979	3112
Barley	6627	7734	7090	7540	7166	7218	8100	14264	10087	11376
Oats	51	117	129	128	49	56	124	175	249	163
Maize	15245	13759	15080	14069	10594	13111	13588	10234	12078	10313
Rice	2163	2319	2325	2721	2080	2245	3170	2073	2652	2816
Sorghum	452	285	252	254	160	2873	112	230	313	235
Peas	126	241	118	175	767	454	747	1444	1016	866
Other Legumes	76	91	1293	72	64	43	9	0	72	66
Seed	0	0	1	0	1	3	12	0	0	0
Potatoes	0	1	2	7	2	0	0	0	0	0
Sunflower	3208	1822	1903	1408	925	876	568	832	576	196
Colza	722	110	77	139	43	36	149	19	48	120
Other industrial crops	232	63	138	85	87	0	0	1	4	3
Tomatoes	26	10	4	11	3	0	0	0	0	2
Onions	105	178	185	136	122	310	201	124	165	209
Other vegetables	10710	11017	10376	10832	10003	11270	9022	8536	11034	11865
Alfalfa	66	106	28	35	34	19	138	58	226	92
Fodder vetches	820	645	1131	1487	1066	1405	2093	2086	2926	3178
Other fodder	99	129	163	139	132	32	24	44	11	11
Other herbaceous	74	64	68	63	69	271	39	65	62	63
Apple trees	101	100	98	101	95	46	51	88	86	88
Pear trees	9	10	10	14	8	17	21	24	25	30
Cherry trees	5	4	3	3	2	1	1	1	1	1
Plum trees	0	0	20	21	15	1	2	16	19	22
Apricot trees	46	54	71	65	80	176	48	103	114	128
Peach trees	167	179	173	223	232	115	181	265	264	234
Almond trees	15	25	23	23	27	54	385	117	141	141
Other fruit trees	444	408	408	423	397	531	451	423	420	415
Olives	1149	1309	1413	1363	1261	1347	1434	1570	1529	1497
Grapes	32	31	31	28	0	0	0	0	0	0
No crop	0	0	0	0	0	2773	2580	905	1866	3800
Mandatory withdrawal	3119	3529	2990	2848	6159	742	963	676	0	0
Voluntary withdrawal	939	2112	891	905	4987	1375	1680	3084	3034	0
Black poplar and other forest	111	89	49	53	41	966	26	67	41	36
Fallow crop	3	6	7	25	46	2	0	83	89	312
Double crops	0	0	0	0	0	0	2048	0	0	2
Dehydrated crops	701	878	904	648	842	383	471	607	963	588
TOTAL	**49190**	**49558**	**49421**	**49250**	**50344**	**50684**	**51595**	**51932**	**52092**	**51979**

Source: Own work based on DGA (2011a [57]).

Table A7. **Cropping patterns in the CGRAA (Ha with high irrigation priority)**

CROPS	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Wheat	2489	5053	4342	5719	4157	5319	7346	9475	5517	8162
Barley	9992	12665	12469	13430	14667	18825	20676	31683	23175	26662
Oats	67	166	193	277	103	106	167	361	328	253
Maize	40712	34978	37001	35417	22688	24258	26723	22361	26412	23494
Rice	5487	5162	5245	6282	4542	4631	6345	4445	5717	6693
Sorghum	678	478	411	460	291	5663	1406	363	637	1009
Peas	310	603	325	502	1653	1215	1138	2385	1825	1813
Other Legumes	179	155	1340	159	141	60	17	11	114	136
Potatoes	73	79	55	34	103	53	12	0	0	0
Sunflower	7532	3993	4660	3117	2084	1644	857	1723	1581	719
Colza	1033	222	132	378	83	58	221	32	76	141
Other industrial crops	504	133	183	114	120	9	20	4	50	3
Tomatoes	48	30	27	56	39	3	29	7	8	13
Onions	0	0	0	21	54	45	0	0	0	0
Other vegetables	329	448	405	303	199	557	371	246	288	330
Alfalfa	29253	30527	31207	31459	29529	30003	25838	22031	26510	27921
Fodder vetches	92	140	50	55	52	162	239	93	362	468
Other fodder	1737	1545	2141	2728	2153	3927	4906	4337	5566	6127
Other herbaceous	219	249	284	485	335	71	69	125	60	68
Apple trees	134	113	138	134	138	612	86	137	130	130
Pear trees	120	116	117	120	124	48	59	104	104	105
Cherry trees	14	13	15	20	13	19	24	35	38	46
Plum trees	11	9	10	12	11	7	3	4	5	5
Apricot trees	1	0	45	46	34	11	6	24	27	30
Peach trees	123	132	199	177	204	274	83	261	262	284
Almond trees	249	263	268	348	371	162	291	429	448	435
Other fruit trees	51	64	84	87	93	107	1107	207	235	239
Olives	601	761	769	789	776	637	692	758	748	739
Grapes	1160	1319	1427	1376	1772	1637	1446	1577	1537	1506
Nursery	32	31	31	28	0	0	0	0	0	0
No crop	0	0	0	0	0	6070	4239	1702	4574	8871
Mandatory withdrawal	6259	7627	6100	5609	13558	2055	2500	1373	25	24
Voluntary withdrawal	2339	4932	2062	2114	12734	4318	4897	8850	7839	253
Black poplar and other forest	173	148	82	88	71	983	108	114	66	72
Unassigned	0	0	0	0	0	3	13	5	0	0
Fallow crop	3	8	8	31	67	34	9	154	143	624
Double crops	0	0	0	0	0	686	3326	0	0	8
Dehydrated crops	1448	1691	2179	1969	2351	1403	1632	1809	2560	1638
TOTAL	**113451**	**113856**	**114005**	**113945**	**115311**	**115619**	**116904**	**117226**	**116969**	**119032**

Source: Own work based on DGA (2011a [57]).

Table A8. **Water requirements in the Monegros area (Dm³)**

CROPS	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Wheat	2146	6666	5522	5847	5639	7968	9834	13588	8416	11892
Barley	6452	9583	10509	11403	14626	22680	24455	34577	25488	29505
Oats	75	226	301	699	240	236	201	851	363	422
Maize	139687	116704	120458	117363	65664	61638	72445	67027	79294	72806
Rice	27771	23756	24422	29813	20603	19962	26521	19882	25694	32528
Sorghum	1110	958	786	1019	649	13741	6350	660	1598	3795
Peas	246	484	277	437	1183	1016	522	1257	1081	1264
Other Legumes	138	87	62	115	85	23	11	15	56	94
Seed	0	0	0	0	0	0	0	0	0	0
Potatoes	324	349	232	123	447	223	0	0	0	0
Sunflower	20671	10381	13153	8150	5388	3683	1377	4267	4705	2436
Colza	1509	545	259	1144	190	108	351	64	135	104
Other industrial crops	1298	341	217	141	160	44	95	14	224	4
Tomatoes	109	98	115	205	182	11	145	34	42	59
Pepper	0	0	0	5	8	0	0	0	0	0
Onions	0	0	0	120	177	259	0	0	0	0
Green beans	0	0	0	0	0	220	0	0	0	17
Other vegetables	830	1005	819	617	363	648	634	453	458	463
Alfalfa	119461	125918	134373	133167	125731	120387	108072	87199	101008	104760
Fodder vetches	30	39	25	22	11	169	117	42	159	438
Other fodder	3495	3435	3858	4721	4080	9583	10711	8592	10043	11251
Other herbaceous	467	466	474	1362	800	148	178	309	188	217
Apple trees	375	311	440	444	434	2138	322	480	453	451
Pear trees	119	97	119	117	111	13	45	86	101	92
Cherry trees	13	9	16	16	14	5	9	47	60	76
Plum trees	41	34	42	55	59	40	15	20	23	23
Apricot trees	5	0	152	154	117	62	28	50	51	51
Peach trees	531	536	826	728	810	666	208	1044	983	1041
Almond trees	437	448	504	662	687	248	581	871	973	1062
Other fruit trees	245	261	415	438	452	375	4712	616	640	677
Olives	450	1019	1040	1054	956	305	695	964	947	932
Grapes	52	49	66	62	70	1373	57	35	38	42
Double crops	0	0	0	0	0	6075	10984	0	0	29
Dehydrated crops	0	0	0	0	0	0	0	0	0	0
TOTAL	**328086**	**303803**	**319484**	**320207**	**249935**	**274049**	**279677**	**243044**	**263217**	**276528**

Source: Own work.

Table A9. **Water requirements in the Cinca area (Dm³)**

CROPS	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Wheat	3443	4748	4399	7399	3890	4275	6939	8288	4450	6934
Barley	11254	13201	12188	12972	12583	12915	14227	25664	18166	20353
Oats	218	520	561	572	229	251	534	773	1100	712
Maize	80337	72749	79818	74080	56680	68804	71299	53597	63371	54288
Rice	17843	19116	19168	22416	17150	18485	26271	17055	21806	23135
Sorghum	2150	1318	1157	1174	740	13551	508	1076	1447	1137
Peas	168	322	157	233	1024	606	997	1927	1356	1156
Other Legumes	101	121	1727	96	104	58	12	0	97	88
Potatoes	1	2	7	30	8	0	0	0	0	0
Sunflower	14478	8208	8685	6274	4265	4017	2603	3761	2572	872
Oilseed rape	3446	527	362	622	201	157	675	90	232	543
Other industrial crops	844	280	667	374	228	0	0	2	2	2
Tomatoes	125	50	20	55	13	1	0	0	0	7
Onions	0	0	0	0	133	0	0	0	0	0
Green beans	0	0	0	0	0	0	0	0	0	13
Other vegetables	388	650	678	505	367	1134	726	460	605	747
Alfalfa	65657	67260	63520	66309	61267	68014	55209	51896	67317	72397
Fodder vetches	76	122	33	40	49	22	159	67	259	106
Other fodder	2979	2356	4120	5438	3926	5230	7672	7616	10619	11520
Other herbaceous	348	463	599	504	482	116	81	159	40	41
Apple trees	484	420	447	418	459	1667	250	427	413	414
Pear trees	586	582	567	591	614	281	306	518	506	518
Cherry trees	39	43	43	60	34	75	95	109	112	133
Plum trees	31	24	21	19	10	7	6	4	5	5
Apricot trees	2	1	126	128	94	5	12	94	108	126
Peach trees	281	326	431	396	487	1082	288	624	694	779
Almond trees	884	948	919	1184	1279	610	960	1402	1400	1243
Other fruit trees	94	159	145	142	167	337	2413	729	885	884
Olives	1279	1174	1174	1218	1278	1529	1298	1219	1208	1195
Grapes	5437	6191	6682	6447	6611	6371	6784	7426	7233	7080
Black poplar and other forest	0	0	0	0	0	0	0	0	0	0
Unassigned	0	0	0	0	0	0	0	0	0	0
Fallow crop	0	0	0	0	0	0	0	0	0	0
Double crops	0	0	0	0	0	0	0	0	0	0
Dehydrated crops	0	0	0	0	0	0	0	0	0	0
TOTAL	**212975**	**201882**	**208420**	**209698**	**174203**	**209602**	**215749**	**184983**	**206004**	**206440**

Source: Own work.

Table A10. **Water requirements in the CGRAA (Dm³)**

CROPS	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Wheat	5589	11414	9922	13246	9528	12243	16773	21876	12866	18826
Barley	17706	22784	22698	24376	27209	35595	38682	60241	43654	49858
Oats	293	746	862	1271	469	487	735	1624	1463	1134
Maize	220024	189453	200276	191442	122344	130442	143744	120623	142664	127094
Rice	45614	42872	43590	52229	37753	38447	52792	36937	47500	55663
Sorghum	3259	2276	1943	2193	1389	27292	6858	1737	3045	4932
Peas	414	805	434	671	2207	1622	1519	3184	2437	2420
Other Legumes	239	208	1789	212	189	81	23	15	152	182
Seed	0	0	0	0	0	0	0	0	0	0
Potatoes	325	352	239	154	455	223	0	0	0	0
Sunflower	35149	18590	21838	14425	9653	7700	3980	8028	7277	3308
Oilseed rape	4955	1071	622	1766	390	265	1026	153	366	647
Other industrial crops	2142	620	884	516	388	44	95	17	226	6
Tomatoes	234	148	135	260	195	12	146	34	43	65
Pepper	0	0	0	5	8	0	0	0	0	0
Onions	0	0	0	120	309	259	0	0	0	0
Green beans	0	0	0	0	0	220	0	0	0	29
Other vegetables	1218	1655	1497	1122	730	1782	1359	913	1063	1210
Alfalfa	185118	193179	197893	199476	186999	188401	163281	139095	168325	177157
Fodder vetches	106	161	58	63	60	191	277	109	418	543
Other fodder	6475	5791	7978	10160	8005	14814	18383	16208	20663	22771
Other herbaceous	815	929	1073	1866	1283	265	259	468	228	258
Apple trees	859	731	887	862	893	3806	572	907	866	865
Pear trees	706	679	685	708	725	294	351	604	606	610
Cherry trees	52	52	59	76	48	80	104	155	172	209
Plum trees	72	58	63	75	69	48	21	25	27	27
Apricot trees	8	1	277	282	211	67	40	144	159	177
Peach trees	811	862	1257	1124	1297	1748	496	1668	1677	1820
Almond trees	1321	1396	1423	1846	1967	858	1541	2273	2374	2304
Other fruit trees	339	420	560	580	619	712	7125	1345	1525	1561
Olives	1729	2193	2214	2272	2234	1834	1993	2183	2155	2128
Grapes	5489	6239	6748	6509	6681	7744	6842	7461	7270	7122
Black poplar and other forest	0	0	0	0	0	0	0	0	0	0
Double crops	0	0	0	0	0	0	0	0	0	0
Dehydrated crops	0	0	0	0	0	6075	26409	0	0	42
TOTAL	**541063**	**505686**	**527905**	**529905**	**424139**	**483651**	**495426**	**428027**	**469221**	**482968**

Source: Own work.

Table A11. **Irrigated and non-irrigated land in the province of Huesca**

	2001				**2002**			
	Irrigated		Non-irrigated		Irrigated		Non-irrigated	
Crops	Ha	%	Ha	%	Ha	%	Ha	%
Wheat	8,226	38%	13,445	62%	14,067	53%	12,352	47%
Barley	25,583	15%	141,323	85%	42,845	21%	161,859	79%
Alfalfa	44,789	95%	2,590	5%	37,999	81%	8,776	19%

	2003				**2004**			
	Irrigated		Non-irrigated		Irrigated		Non-irrigated	
Crops	Ha	%	Ha	%	Ha	%	Ha	%
Wheat	11,729	39%	18,392	61%	10,312	48%	11,396	52%
Barley	29,450	16%	153,859	84%	29,624	16%	149,917	84%
Alfalfa	47,411	94%	2,897	6%	47,000	89%	5,707	11%

	2005				**2006**			
	Irrigated		Non-irrigated		Irrigated		Non-irrigated	
Crops	Ha	%	Ha	%	Ha	%	Ha	%
Wheat	10,302	39%	16,186	61%	13,071	52%	12,305	48%
Barley	32,179	18%	151,334	82%	42,669	22%	148,589	78%
Alfalfa	42,048	94%	2,493	6%	43,504	86%	7,089	14%

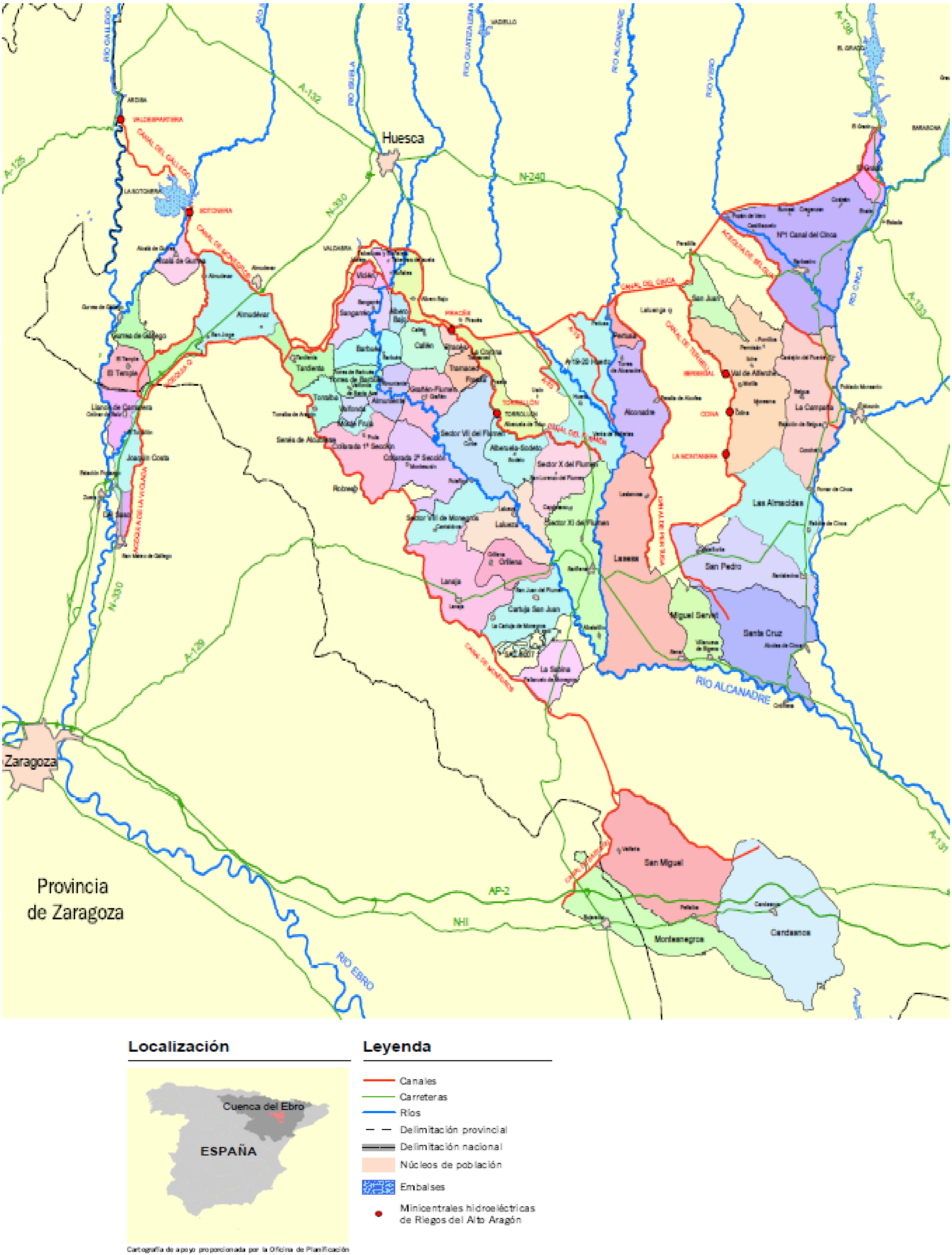
	2007				**2008**			
	Irrigated		Non-irrigated		Irrigated		Non-irrigated	
Crops	Ha	%	Ha	%	Ha	%	Ha	%
Wheat	15,832	57%	11,720	43%	20,093	57%	15,392	43%
Barley	45,772	23%	153,969	77%	52,691	24%	170,914	76%
Alfalfa	37,951	82%	8,064	18%	32,973	84%	6,359	16%

	2009				**2010**			
	Irrigated		Non-irrigated		Irrigated		Non-irrigated	
Crops	Ha	%	Ha	%	Ha	%	Ha	%
Wheat	14,067	53%	12,352	47%	16,828	47%	18,901	53%
Barley	42,845	21%	161,859	79%	45,944	23%	151,891	77%
Alfalfa	37,999	81%	8,776	19%	40,249	81%	9,357	19%

	Average 2001-2010	
Crops	Irrigated	Non-irrigated
Wheat	48%	52%
Barley	20%	80%
Alfalfa	87%	13%

Source: Own work based on DGA (2011b [58]).

Map A1. **Irrigation sub-schemes in the CGRAA**



Source: CGRAA.

Chapter 2

Methodology: Computable General Equilibrium models

2.1. Introduction

The core of this thesis addresses the issues related to water management in the province of Huesca using the methodology of computable general equilibrium models. After analysing the water situation in the Upper Aragon Irrigation Scheme, we present the main methodology of the thesis in this chapter, as used in the empirical applications described in the following chapters.

2.1.1. Background

The origin of the theory of general equilibrium was constructed by Leon Walras in his *Elements of Pure Political Economy* (1874 [185]), which is the basis of computable general equilibrium models. However, Quesnay had in fact already used the *tableau économique* to show the relationships between agriculture and other sectors in the eighteenth century. In the 1930s, Leontief developed input-output analysis focusing on the interrelationships in production systems, and he was awarded the Nobel Prize in 1973. As Roux (2006 [156]) notes, the usefulness of input-output analysis comes from its ability to anticipate consequences in all economic sectors of a decision that may initially seem to concern only one, a capacity that is due precisely to the general equilibrium.

Thanks to the extension of mathematical methods, Arrow and Debreu (1954 [9]) were able to develop the first full nonlinear general equilibrium model in the 1950s, and even to demonstrate the existence of equilibrium. The Nobel Prize was awarded to Arrow in 1972, for his pioneering research in general equilibrium theory and later to Debreu (1983).

In the 1960s, the first applications of CGE models were developed by Johansen (1960 [99]), who studied the sources of growth in the Norwegian economy, and by Harberger (1962 [90]), who calculated the impact of tax changes on welfare in the American economy. According to Ballard *et al*. (1985 [17]), these initial models were difficult to handle because of the high level of aggregation – only two sectors or countries, two factors and two goods. However, a big step forward was achieved some years later by Scarf and Hansen (1973 [168]), who developed the computational algorithm needed to solve the equilibrium in computable general equilibrium models.

This encouraged applications of the methodology in the last two decades of the twentieth century using software programmes which allowed mathematical calculations based on large amounts of data. Since then, numerous central banks and public institutions have developed general equilibrium models to analyse different economic policy scenarios, including the Central Bank of Nicaragua (Gámez, 2008 [78]), the World Bank (Löfgren and Díaz-Bonilla, 2010 [112]), institutions such as the International Food Policy Research Institute (IFPRI) (Löfgren *et al*., 2002 [111]) and the Global Trade Analysis Project (GTAP) (Hertel, 1997 [93]), which allows modelling of the global economy. The University of Melbourne (Dixon *et al*., 1982 [66]) also built the ORANI model, originally for the Australian economy although it has subsequently been applied in countries like China, Brazil, Japan, Venezuela and Taiwan. Meanwhile, Monash University, also in Australia, developed its successor in the IMPACT project and is currently developing several dynamic computable general equilibrium models such as MONASH and MMRF-Green with regional and environmental features. Recently, the PACE model (*Policy Analysis based on Computable Equilibrium*) was developed by Böhringer *et al*. (2002 [29]) for use by the European Commission in the design and implementation of climate change and renewable energy measures with a 2020 time horizon. A review of the main models used by international institutions will be found in Böhringer and Löschel (2006 [30]).

The early models were static models under perfect competition and were based on standard neoclassical structure (in other words, Walrasian style). Such models currently offer a wide range of possibilities and capture a variety of economic behaviours through instruments such as flexible pricing, taxation, imperfect competition with increasing returns, and different structures for constant elasticity of substitution (CES) nested functions. Furthermore, they may also impose a broad spectrum of macro criteria[24] (Taylor 1990 [175], 2004 [176]; and Robinson, 2006 [154]).

Early dynamic general equilibrium models were developed around 1995 to make predictions in the medium and long term. These models can be classified as intertemporal dynamic models or recursive models. A recursive dynamic model is basically a series of static models related to each period by exogenous and endogenous variables allowing annual updates. Intertemporal dynamic or Ramsey-type models are based on the theory of optimal growth with rational expectations, which posits that agents do not only consider the current state of the economy, but also situations that affect their present and future welfare (Dellink *et al*., 2011 [52]). A detailed explanation of the Ramsey model can be found in Sala-i-Martín (2005 [159]) and the main differences between intertemporal and recursive dynamic models are described in Babiker *et al*. (2009 [12]).

In recent years, computable general equilibrium models have increasingly been solved as mixed complementarity problems rather than optimisation problems with nonlinear programming, based on systems such as Mathematic Programming System for General Equilibrium Analysis (MPSGE) (see Rutherford, 1999 [157]; Markusen and Rutherford, 2004 [122]). This system greatly simplifies the coding language and the equations expressing the models, making it easier to solve simulations which include water and energy as inputs, increasing returns or dynamic situations. Böhringer *et al.* (2007 [32]) show that computation using mixed complementarity provides a better analysis of policy scenarios involving market failure or distortionary taxes.

2.1.2. A brief review of applications to water management

Computable general equilibrium models developed over the last 20 years have attempted to resolve a wide variety of economic problems. Many papers have focused on the analysis of issues related to fiscal policy and foreign trade, but the literature also presents models that have been applied to water management. The use of general

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[24] These models include structural features which change relevant neoclassical criteria.

equilibrium models is nowadays considered a methodological approach to the design and statement of hydro-economic models.

Research using static computable general equilibrium models to focus on solving the problems of water scarcity includes Berck *et al*. (1991 [22]), who examine the utility of reducing water use in agriculture in order to solve drainage problems in the San Joaquin Valley in California; Berrittella *et al*. (2007 [24]), who consider the implications of water supply constraints in arid countries; Strzepek *et al*. (2008 [173]), who estimate the economic benefits of the Aswan High Dam in Egypt; and Van Heerden *et al*. (2008 [182]), who apply the technique to the two most water-intensive sectors in South Africa. Others studies analyse the effects of water reallocation, including Seung *et al*. (1998 [170]), who consider the Walker River Basin in Nevada and California, and Gómez *et al*. (2004 [85]) and Tirado *et al*. (2006 [178]), who apply CGE models to the Balearic Islands in Spain.

The suitability and usefulness of general equilibrium models for the analysis of water pricing policies (Brower and Hofkes, 2008 [36]) has encouraged numerous scholars to investigate the economic implications of these policies. For example, Decaluwé *et al*. (1999 [48]) apply CGE techniques to the Moroccan economy, Berrittella *et al*. (2006 [23]) to the global economy, Velázquez *et al*. (2006 [183]) to a regional economy in Spain, and Llop and Ponce-Alifonso (2012 [110]) to the Catalan economy. Finally, Calzadilla *et al*. (2010 [39]) propose a model to observe the overall impact of efficiency gains in the use of irrigation water.

Water is a long-term matter, and therefore dynamic general equilibrium models have also been applied to analyse and simulate water management over long periods. For instance, Goodman (2000 [82]) used an intertemporal dynamic model to show that water transfers are less expensive than building new reservoirs for the Arkansas River Basin. Meanwhile, Diao and Roe (2003 [62]) use an intertemporal dynamic model to analyse water policy and trade in Morocco, and Briand (2006 [34]) has studied the effects of a combination of climatic shocks and water pricing policies using a recursive model with imperfect competition in Senegal. Feng *et al*. (2007 [76]) uses a recursive dynamic model to analyse the economic implications of an increase in the water supply in relation to the project to transfer water from southern to northern China (SNWT). Faust *et al*. (2012 [74]) also analyse the impacts of changes in water availability in the Swiss economy using a recursive model. Finally, Robinson and Gueneau (2013 [155]) combine a dynamic general equilibrium model with a regional water distribution model to analyse the economic impact of changes in water resources in the basin of the Indus River in Pakistan.

This brief review reflects the appropriateness of computable general equilibrium models for purposes of our analysis, justifying its use here. Additional and more extensive information on other applications will be found, for example, in Cañada and Toledo (2000 [40]), O'Ryan *et al.* (2003 [136]), Cardenete and Llop (2005 [41]), Sánchez-García (2005 [165]) and Cardenete (2009 [42]).

2.1.3. A brief review of CGE models & stochastic programming

A number of studies have addressed the role of uncertainty in climate change and in technological change, the subject of chapter 5 of this thesis. Specifically, a review of papers dealing with uncertainty in different areas such as climate damage, technological change and emissions policies will be found in Baker and Shittu (2008 [14]). This review discusses various conclusions from these studies and highlights the different lines of research. Recently, Pratt *et al*. (2013 [146]) also present a review of computable general equilibrium models that consider risk, and even quantify the monetary value of risk by incorporating uncertainty in a computable general equilibrium model.

Baker *et al.* (2007 [13]) demonstrate the relevance of incorporating the uncertainty inherent in climate change and technological change in climate change policy analysis, treating the uncertainty inherent in technological change as endogenous.

Böhringer and Rutherford (2006 [31]) use stochastic programming to analyse the optimal policy mix between taxing emissions and subsidising technologies in Research and Development (R&D) programs, taking into account the date at which the advanced technology becomes available, anticipating some of the questions we raise in chapter 5. These authors found that R&D was an attractive substitute for emissions taxes in their scenario, and the uncertainty inherent in technological change pointed to a lower carbon tax. This shows that the implications of uncertainty cannot always be inferred from sensitivity analysis (Baker and Shittu, 2008 [14]).

Durand-Lasserve *et al*. (2010 [69]) show how uncertainty about the 2020–2050 emissions targets may affect CO_2 and energy prices, as well as technological choices in the energy sector. To do so, they develop stochastic policy scenarios within a computable general equilibrium framework to analyse CO_2 prices.

In the case of developing countries, Arndt *et al*. (2011 [8]) extend the model developed by Löfgren *et al*. (2002 [111]) to include a stochastic approach to the analysis of economic impacts from climate change and potential adaptation policies in Ethiopia. Their findings suggest that investments in water resource management infrastructure should be an integral component of any climate change adaptation strategy to reduce the effects of global warming.

Finally, the findings obtained from any model require a sensitivity analysis to validate the policy implications. The selection of parameters in a computable general equilibrium model could be considered subjective and so, therefore, could affect the results obtained in the simulations. In this case, uncertainty is related to the risk of reporting incorrect results (Pratt *et al*., 2013 [146]). In practice, sensitivity analyses are usually limited to certain specific aspects because they can be numerically difficult. In the last few years, however, a number of sophisticated techniques have been developed to facilitate estimation. The inclusion of stochastic elements in a computable general equilibrium model can thus be highly beneficial and effective.

Examples include the PACE model, which has stimulated a number of subsequent studies to assess the robustness of results. For example, Böhringer *et al.* (2009 [33]) evaluated the economic impacts of EU climate policies, including sensitivity analyses on the implications, and Hermeling *et al*. (2013 [92]) include a new method based on stochastic sensitivity analysis. Similarly, in this work, we perform a sensitivity analysis on the parameters selected for the elasticity of substitution between capital and water factors.

2.1.4. Study limitations

A good analysis of results requires, in the first place, awareness of the limitations which may exist due both to the methodology and to the issue in question. Computable general equilibrium models allow a high degree of sector disaggregation and provide good estimates of the impacts of economic policy variables such as income distribution, relative prices and production levels. Furthermore, they are better able to register the effects of feedback and to calculate both equilibrium prices and quantities than input-output models and those based on social accounting matrices (see Robinson, 2006 [154]). Nevertheless, computable general equilibrium models also have their limitations. Based on the work of O’Ryan *et al*. (2003 [136]) and Sánchez-García (2005 [165]), we may note the following:

- They require large data bases, which makes them dependent on the quality of statistical sources.
- Equations must be calibrated so that the parameters estimated depend on the data used in the base year.
- It is difficult to deal with monetary and financial issues. However, a number of interesting papers have been published in this field, including Robinson (1991 [153]), Tarp and Tarp (2002 [174]) and Agenor *et al*. (2009 [3]).
- Additional parameters are required in dynamic models.
- Finally, these models assume competitive and balanced markets in the baseline.

With regard to the subject of the present study, we may note that computable general equilibrium models are also subject to certain limitations when it comes to capturing detailed hydrological processes. McKinney *et al*. (1999 [130]) identify the following, which are also discussed in Brower and Hofkes (2008 [36]):

- Hydrological models are often based on simulation techniques without optimisation, while economic models always include optimisation processes.
- Watersheds and river basins are usually the geographical unit of hydrological models, while economic models often refer to the administrative boundaries of a region (municipality, province, state) or to a country as a whole.
- The time periods in hydrologic models often refer to days, months or seasons (summer and winter), while economic models generally have longer reference periods (normally years).

However, this thesis seeks to overcome or mitigate these limitations. Specifically, the empirical application described in the third chapter is addressed using direct optimisation (in line with the IFPRI model), but the dynamic model proposed in the fourth chapter is solved as a mixed complementarity problem, which is also based on optimisation but is much more flexible. Furthermore, with respect to the limitations of the geographical unit, the economy of Huesca province is dominated by the Upper Aragon Irrigation Scheme, which is representative of irrigation in the Ebro Valley. Therefore, the combination of information obtained both from the province of Huesca and from the CGRAA and some rivers and reservoirs located in the region allows reliable applications of the main features of the economic models used in the thesis.

Finally, empirical applications are inevitably affected by the difficulties associated with the quantification of virtual water and measures of the respective responsibility of direct and indirect users. The indirect benefits of irrigation water are enjoyed mainly by the agri-food industry, hotels and restaurants, exporters and end users. In this light, a policy to share water costs among all users would be highly complex and naturally very difficult to model. These matters are considered in more detail in the third chapter.

2.2. Solving CGE models

Any computable general equilibrium model will be solved by means of an optimisation process, defined by an objective function, variables and constraints. Optimisation models can be developed using different algebraic modelling languages which facilitate calibration and the achievement of the equilibrium, like GAMS (General Algebraic Modelling System), the characteristics of which are described in Brooke *et al*. (1998 [35]). We shall work with this language here.

GAMS enables computable general equilibrium models to be solved in two ways. The conventional approach is to treat the model as a nonlinear optimisation problem (NLP) and to solve it using specific optimisation algorithms like CONOPT. The second approach solves the model as a mixed complementarity problem (MCP) by including the corresponding equations and inequalities. In the latter case, the language system used is generally GAMS/MPSGE, which can significantly simplify coding by using MILES solver, and for more sophisticated and complex models PATH solver, which is documented in Dirkse and Ferris (1995 [65]). More detailed calculation algorithms, and a discussion of the peculiarities of these methods will be found in Gómez Gómez-Plana (1999 [83]), Paltsev (2000 [139]), González-Eguino (2006 [86]) and Ramos *et al*. (2010 [150]).

The mathematical equivalence between the conventional approach to estimating the general equilibrium with nonlinear programming and mixed complementarity is demonstrated in Ferris and Sinapiromsaran (2000 [77]). As Gómez Gómez-Plana (2005 [84]) explains, these authors show that Karush-Kuhn-Tucker conditions are equivalent to the problem in the nonlinear mixed complementarity approach. Gómez Gómez-Plana (2005 [84]) also highlights some of the advantages of the mixed complementarity method. First, it makes use of duality theory, simplifying the presentation of the models through complementary slackness conditions, which are equivalent to the first order conditions of the dual problem of nonlinear programming. Secondly, the use of complementarity avoids the problem of integrability by not directly presenting utility functions but demand functions. This feature is even more relevant when taxes are included in the model structure and the resulting allocation of the model is not efficient.

In the following chapters we shall work with both methods. The third chapter describes a computable general equilibrium model following the static IFPRI model documented in Löfgren *et al*. (2002 [111]), which is solved as an optimisation problem with nonlinear programming. In the fourth and fifth chapters, we develop two dynamic computable general equilibrium models both of which are solved as a mixed complementarity problem using the GAMS/MPSGE language system. Appendix B in Section 2.6 shows the resolution of a simple example with MCP using GAMS in a standard form and also the MPSGE. This comparison clearly displays the advantages of the MPSGE language.

2.2.1. SAM used for calibration

Computable general equilibrium models generally start from a Social Accounting Matrix (SAM) which represents the initial equilibrium (see Kehoe, 1996 [102]). A SAM is an extension of an input-output table to which the structure of disaggregated expenditure and income is added. This helps overcome the limitations of the tables in relation to non-directly productive economic relations such as investment, savings, foreign trade, taxes, household consumption, etc. The additional information is obtained primarily from the National Accounts and the Household Budget Survey. After obtaining the SAM, or the initial balance of the computable general equilibrium model, which is of course the same thing, we proceed to calibration of the model by obtaining the parameters of different specific functional forms of the model from the SAM data. Further information about this calibration process is provided in Mansur and Whalley (1984 [116]).

The Social Accounting Matrix used in the following chapters will be the SAM for the province of Huesca in 2002, which was obtained from Cazcarro *et al*. (2010 [43]). The information contained in this SAM was obtained from the Agrarian National Accounts published by the Spanish Ministry of Agriculture, Fisheries and Food, the National Institute of Statistics and the Statistical Institute of Aragon. In the Final

Appendix of this thesis, we show the SAM actually used in later chapters, which was obtained after making some modifications as we explain in this section.

There are several reasons for using the 2002 SAM for Huesca. In the first place, it has a high level of disaggregation. The farm sector is broken down into agriculture and livestock, and agriculture is turn split into irrigated and non-irrigated land. Finally, irrigated agriculture is disaggregated into 32 sectors according to crop types such as wheat, barley, maize, etc. This provided a high degree of disaggregation for the main sector for which the empirical applications were designed, at the same time allowing selection of the most appropriate level of aggregation according to the objectives proposed. Specifically, irrigated agriculture is aggregated into only one sector in the third chapter because policies affect all water users in the same way. In the fourth chapter, however, irrigated agriculture is broken down into four crop groups in order to discuss the reallocation of water after the application of different economic policies and evaluating the effects on cropping patterns.[25]

Second, the province of Huesca was chosen for the study because it includes the Upper Aragon Irrigation Scheme (CGRAA), Spain’s largest irrigation scheme, which encompasses 58 irrigation sub-schemes and also supplies numerous towns in the provinces of Huesca and Zaragoza and 10 industrial estates. The main advantage of this choice was the availability of highly relevant information on water use, levels of efficiency, cropping patterns, etc. from 2001 to 2010, as explained in the previous chapter. This information is of vital importance to understanding the real situation of water demand in the region, and for the design of economic policies to solve the problems identified.

Finally, 2002, the base year for the SAM, saw average rainfall year, which is important for the analysis of a semi-arid region that is prone to irregular drought. The input-output framework available for 2005 could also have been used, but we opted against this course because 2005 was the driest of the decade, as mentioned in the previous chapter.

---

[25] This SAM is given in the Final Appendix. See also Table B1 of Appendix B, which lists the SAM accounts.

2.2.2. Water as a production factor

Since the Dublin Conference on Water and the Environment (ICWE, 1992 [96]), it has been generally agreed that water should be treated as an economic good, given resource scarcity caused by competing water uses (Brower and Hofkes, 2008 [36]). Table 2.1 shows the four principles established at the Dublin conference. However, what this actually entails is a matter of interpretation. Some believe water should be classed as a commodity, while others view it as a social asset which should be allocated outside the market in a process of integrated decision-making on the allocation of scarce resources (Savenije and van der Zaag, 2002 [167], Aguilera, 2006 [4], Llop and Ponce-Alifonso, 2012 [110]).

Table 2.1. **The Four Dublin Principles**

1. Water is a finite, vulnerable and essential resource which should be managed in an integrated manner.
2. Water resources development and management should be based on a participatory approach, involving all relevant stakeholders.
3. Women play a central role in the provision, management and safeguarding of water.
4. Water has an economic value and should be recognized as an economic good, taking into account affordability and equity criteria.

Source: ICWE (1992 [96]).

In this controversial context, we have sought new strategies for the implementation of water policies. For this reason, water is introduced as a productive factor, which reflects both consumption in irrigated agriculture and in other sectors. This enables analysis of water policies observing the variation of water uses, integration of the evolution of water availability studied and its economic impact as explained in the first chapter, and the design water management policies based on instruments which act on prices and on the quantities of water consumed.

In particular, in the driest year (2005) the volume of water demand for irrigation was significantly reduced, while the water demand for industry and urban supply increased (see Table 1.2), as we saw in the first chapter. In this light, the regulatory preference accorded to industrial and urban demand for water over agricultural demand for agricultural use cannot be ignored. Consequently, we have endeavoured in the fourth chapter to design strategies which address water constraints exclusively in irrigated agriculture, since water demand for industrial and urban use is often unaffected even in dry years. In the third chapter, however, we will also address the criteria for water allocation among paying users and for the modernisation of irrigation (the WFD requires recovery of costs).

The water consumption data in each sector were obtained from Cazcarro *et al.* (2010 [43]), and water prices for industrial accounts are taken from AEAS (2002 [1]) and, in the case of irrigation accounts, from Groot (2006 [89]). As we shall see in the following chapters, an important decision for any modeller is to select the level of substitution between goods and factors of production. In the third chapter, water as a productive factor is substituted by other factors of production (labour and capital) under a CES function. However, the use of the MPSGE system language in the fourth chapter allows us to be more specific in the substitution of water by other factors depending on the sector (see Figures 2.2 and 2.3). Specifically, we include nested levels which allow the water factor to be combined with the aggregate of capital and land, following Gómez *et al.* (2004 [85]) and Goodman (2000 [82]). In addition, the irrigated agriculture sector is broken down by crop type, which means that different values for the elasticity of substitution between capital and water depending on crops can be included. As explained in chapter four, we can therefore incorporate the fact that farmers facing a decrease in the available volume of water will respond by reallocating their resources (land and capital) from one crop to another.

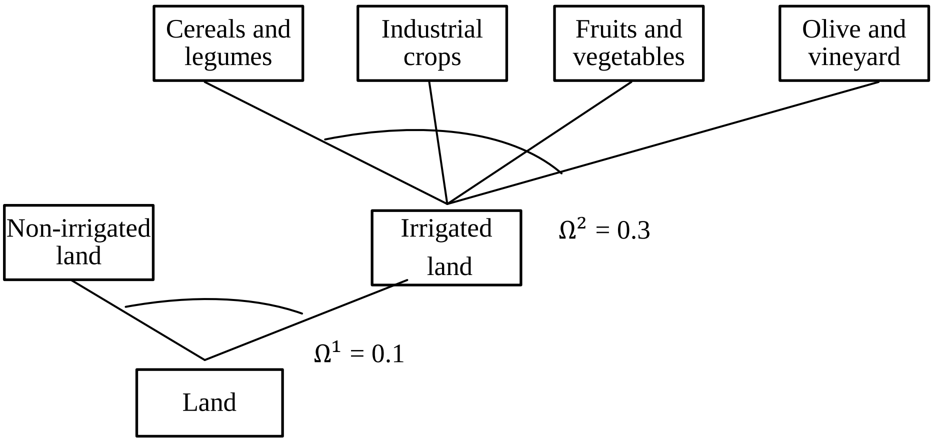
2.2.3. Inclusion of the land factor

Based on the analysis contained in the first chapter, the land factor can play a key role in the implementation of irrigation water policies, due to the limits imposed by the availability of water on the expansion of the irrigated area and cropping patterns. In this light, we include land as a productive factor in the fourth chapter. Basic information is obtained from the irrigated and non-irrigated land data provided by the Regional Government of Aragon (DGA, 2011b [58]) and the distribution of land rights in the agricultural area published by the Aragon Statistics Institute (IAEST, 2003 [95]). The economic contribution of the land factor is approximated by the cost of rights to use land, which we estimated using Ministry of Agriculture, Fisheries and Food data on rentals paid by type of crop in Aragon in 2002 (MAPA, 2002 [117]).

The standard way to integrate the different types and uses of land within a general equilibrium framework is through a Constant Elasticity of Transformation (CET) function (see OECD, 2003 [135]; Birur *et al*., 2008 [26]; Boeters *et al*., 2008 [28]). Specifying a CET assumes transformation between the different possible uses (for further details, see Boeters *et al*., 2008 [28]). This approach is the most common and it allows analysis of changes in cropping patterns in line with the objectives of the study. The literature on the choice of the CET elasticity value is somewhat thin, especially as regards studies analysing the use of water. Most of the papers which examine the land supply in fact tend to focus on biofuels and energy. For the present purposes, we selected the CET values in the baseline scenario on the basis of the characteristics of the region, following OECD guidelines (2003 [135]) (see Table 4.1 in the fourth chapter).

Specifically, we adopted a nested CET function which allocates land in two tiers as shown in Figure 2.1 and equations 2.1 and 2.2, in line with Banse *et al*. (2008 [19]), Birur *et al*. (2008 [26]) and Yang *et al*. (2009 [188]). The tiers comprise the optimal allocation of a given field to land types (e.g. non-irrigated or irrigated) in the first stage, and the choice of crops, which is made in the second stage. This permits observation of the trend in cropping patterns.

Figure 2.1. **Land factor allocation**



Source: Own work.

$$
\begin{aligned}
TT_t &= CET\left(TNR_t, TR_{irri,t}; \Omega^1\right) \\
&= \gamma_t \cdot \left(a_{il} \cdot (TNR_t - \mu_t)^{\frac{\Omega^1 - 1}{\Omega^1}} + (1 - a_{il}) \cdot (TR_{irri,t} + \mu_t)^{\frac{\Omega^1 - 1}{\Omega^1}}\right)^{\frac{\Omega^1}{\Omega^1 - 1}}, \\
&\forall (irri \in il \in i, t)
\end{aligned}
\qquad \text{Eq.(2.1)}
$$

$$
\begin{aligned}
TR_{irri,t} &= CET\left(TR_{irri,t}; \Omega^2\right) \\
&= \vartheta_t (a_1 \cdot TR_{1,t}^{\frac{\Omega^2 - 1}{\Omega^2}} + \cdots + a_i \cdot TR_{irri,t}^{\frac{\Omega^2 - 1}{\Omega^2}})^{\frac{\Omega^2}{\Omega^2 - 1}}, \forall (irri, t)
\end{aligned}
\qquad \text{Eq.(2.2)}
$$

TT_t is the total supply of land, while TNR_t denotes non-irrigated land and $TR_{irri,t}$ irrigated land. The Ω parameter reflects the elasticity of transformation values, and the μ_t parameter represents technological change implying an increase in the extension of irrigated land by a quantity of μ_t through transformation from non-irrigated land to irrigated land, as we will explain in section 2.4.8. The *i* index relates to all sectors, the *il* index relates to sectors which include the land factor (irrigated and non-irrigated agriculture), the *irri* index refers to irrigated agriculture sectors and the *t* index relates to time (see Table B5 in Appendix B in this chapter).

2.3. Overview of the static model specified in Chapter 3

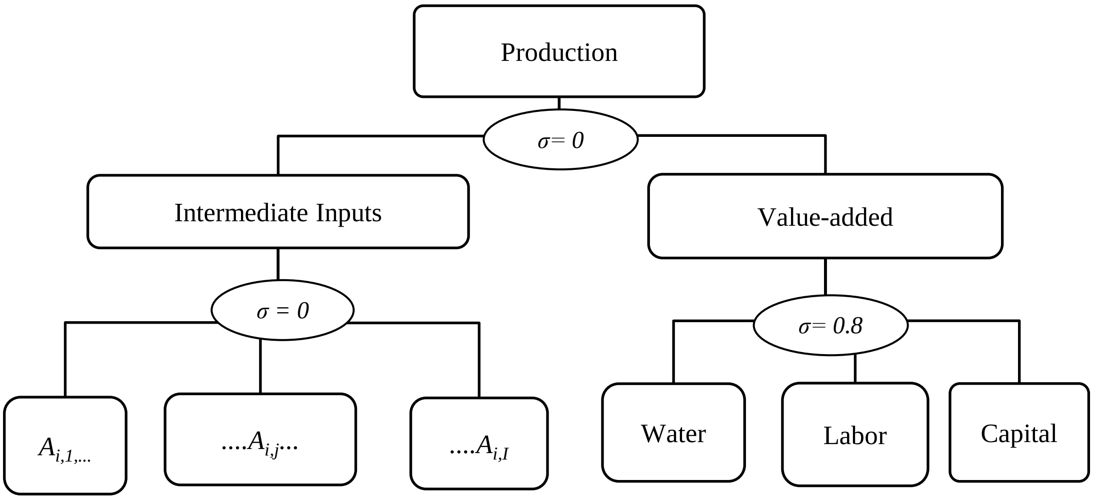
Before examining the dynamic models developed in chapters 4 and 5 in detail, this section briefly presents the main features of the model applied in the chapter 3, which is based on the IFPRI model. However, the model is described in more detail in chapter 3. A detailed explanation of the model will be found in Löfgren *et al*. (2002 [111]). Equations, parameters and variables are presented in Appendix B in section 2.5.

First, perfect competition is assumed to prevail in the model. Each producer (represented by an activity) maximises profits subject to the production technology used. The production functions used are fixed proportions functions (Leontief functions), except in irrigated agriculture, for which a CES function is used, allowing a more straightforward approach to the efficiency gains obtained through the modernisation of irrigation included. Total production is obtained through a combination of aggregate intermediate inputs and value added. Figure 2.2 provides a comprehensive overview of production technology for the irrigated agriculture sector.

In the second level of nesting, the value added in each sector allows combination of the production factors (labour, capital and water) using a CES function.

In the model, institutions comprise households, firms, government and the foreign sector. Households maximise a "Stone-Geary" utility function subject to a linear constraint on spending. In particular, the model does not include self-production by households, which simplifies their optimising behaviour. The government receives income from tax receipts and transfers from other institutions. This income is used to buy goods for consumption and make transfers to other institutions. Firms receive factor income and may also receive transfers from other institutions, government or elsewhere. Firms' revenues are allocated to the payment of direct taxes, savings and transfers to other institutions. With regard to the foreign sector, the model incorporates imperfect substitutability between domestic and imported goods, following the work of Paul Armington (1969 [7]), as well as constant elasticity of transformation functions for exports.

Figure 2.2. **Production structure of the static model for irrigated agriculture sector**



Source: Own work.

Finally, the model determines only relative prices, and the consumer price index (CPI in Appendix B of this chapter) reflects the selected price as the *numeraire*. As explained in the third chapter, the exchange rate between the province of Huesca and foreign trade is fixed. Trade is mostly with the rest of Spain and the European Union and is conducted in the same currency (euros).

2.4. Dynamic model

The main features of the dynamic model specified for empirical application in chapters 4 and 5 are presented in this section. We present the functional forms of the different productive sectors and agents following González-Eguino (2011 [88]) and González-Eguino and Dellink (2006 [87]). A list of the model's parameters and variables is provided in Tables B5, B6 and B7 of Appendix B, subsection 2.5.3.

2.4.1. Producers

Producers maximise their profit subject to certain technological constraints combining optimally intermediate inputs and factors of production. Each production sector *i* produces a homogeneous good by a nesting of different types of functions (CES, Leontief (LT), Cobb-Douglas) that combine inputs in a way more or less flexible depending on the elasticities of substitution. The σ parameters represent the different elasticities of substitution. The production of each sector *i* is obtained in each time *t* by combining intermediate inputs ($Y_{i,t}^{ID}$) and value added ($qva_{i,t}$) with a Leontief function.

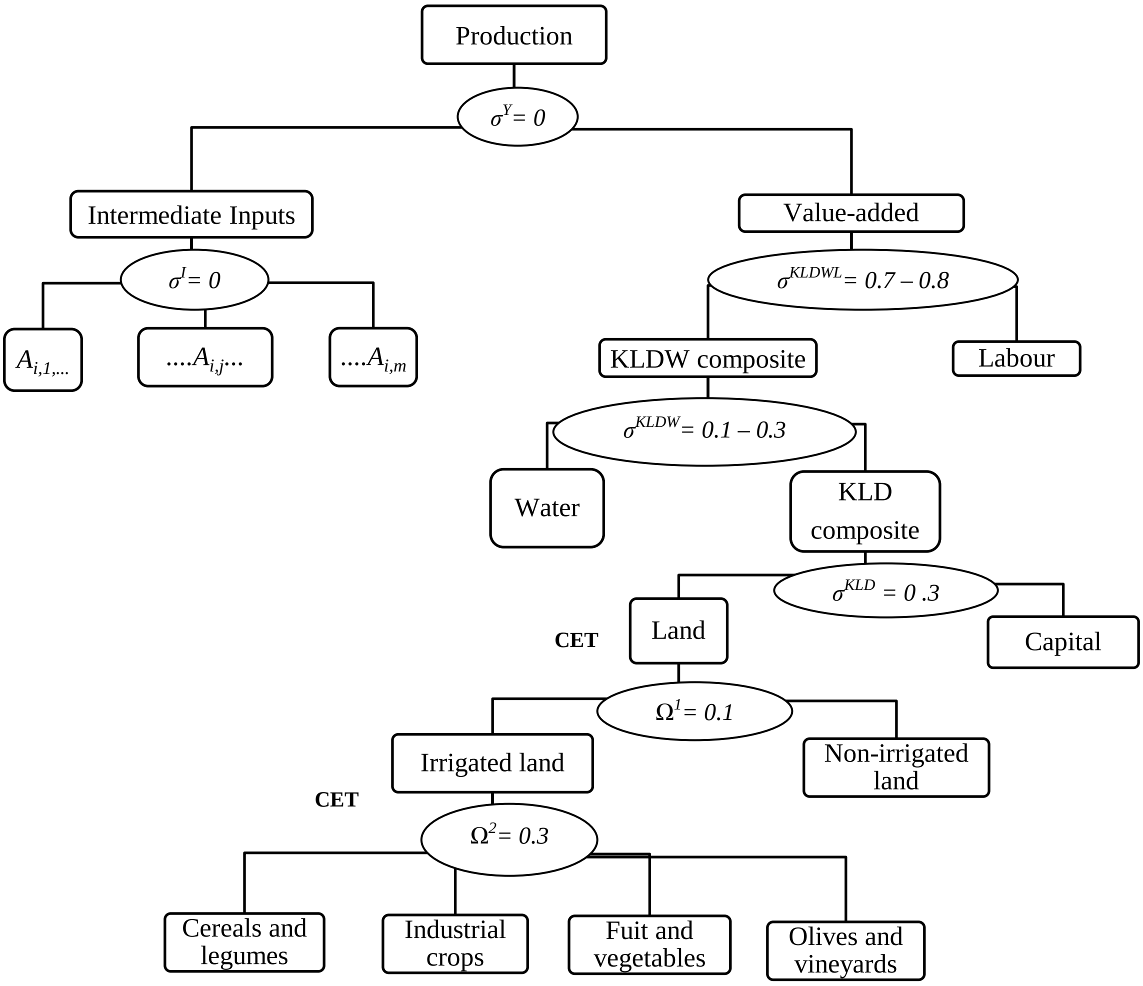
$$Y_{i,t} = LT\left(Y_{i,t}^{ID};\ qva_{i,t}; \sigma^{Y}\right), \forall(i,t) \qquad \text{(Eq.2.3)}$$

The condition of zero profits establishes that the output value for each producer must be equal to the value of all inputs. The output price of sector *i* at time *t* is represented by $P_{i,t}$, the intermediate inputs price is denoted by $PQ_{i,t}$ and the price of value added is $Pva_{i,t}$.

$$P_{i,t} \cdot Y_{i,t} - \left[PQ_{i,t} \cdot Y_{i,t}^{ID} + \left(Pva_{i,t} \cdot qva_{i,t}\right)\right] = 0, \forall(i,t) \qquad \text{(Eq.2.4)}$$

Figure 2.3 presents an overview of the model production technology for irrigated agriculture sectors. We can then see the structure of production in other sectors. In particular, we can differentiate three different structures. Three different structures can be distinguished. The first involves irrigated agriculture sectors which combine all of the factors of production (labour, capital, land and water). The second groups the non-irrigated agriculture sector, which does not use water factor, and the third groups other sectors that use water factor but not the land factor. Figures 2.3, 2.4 and 2.5 provide a visual representation of these situations.

Figure 2.3. **Production structure for irrigated agriculture sectors**



Note: The land module uses CET functions, whereas the rest of the model uses CES functions.

Source: Own work.

The amount of value added in the irrigated agriculture sectors ($irri$) is modelled by a CES function between labour($L_{i,t}$), and aggregate capital-land-water ($KLDW_{i,t}$). The elasticity of substitution between aggregate $KLDW_{i,t}$ and labour factor (σ^{KLDWL}) is slightly lower in agricultural sectors due to the relevance of aggregate $KLDW_{i,t}$ (Jomini *et al*., 1991 [100]).

$$qva_{i,t} = CES\left(L_{i,t}; KLDW_{i,t}; \sigma^{KLDWL}\right) =$$

$$\alpha_i(a_i \cdot L_{i,t}{}^{\frac{\sigma^{KLDWL}-1}{\sigma^{KLDWL}}} + (1-a_i) \cdot KLDW_{i,t}{}^{\frac{\sigma^{KLDWL}-1}{\sigma^{KLDWL}}})^{\frac{\sigma^{KLDWL}}{\sigma^{KLDWL}-1}}, \forall(i = irri, t) \qquad \text{(Eq.2.5)}$$

Aggregate $KLDW_{i,t}$ is modelled by a CES function between the water factor ($W_{i,t}$) and aggregate capital-land ($KLD_{i,t}$). The elasticity of substitution between aggregate $KLD_{i,t}$ and the water factor (σ^{KLDW}) is determined by the irrigation technology applied to each crop, following Gómez *et al*. (2004 [85]). The faster adjustment for spray and sprinkler irrigation crops as cereals and industrial crops is included through the 0.3 elasticity value. A value of 0.1 is applied in the case of drip irrigation used to water crops like olives and vineyards. The value applied to the other irrigated crops like fruit and vegetables is 0.2.

$$KLDW_{i,t} = CES\left(KLD_{i,t}; W_{i,t};\ \varphi; \sigma^{KLDW}\right) =$$

$$\alpha_i(a_i \cdot KLD_{i,t}{}^{\frac{\sigma^{KLDW}-1}{\sigma^{KLDW}}} + (1-a_i) \cdot (\varphi_t \cdot W_{i,t})^{\frac{\sigma^{KLDW}-1}{\sigma^{KLDW}}})^{\frac{\sigma^{KLDW}}{\sigma^{KLDW}-1}}, \forall(i = irri, t) \qquad \text{(Eq.2.6)}$$

At the next nested level, aggregate $KLD_{i,t}$ combines land and capital following Decaluwé *et al*. (1999 [48]) and Gómez *et al*. (2004 [85]).

$$KLD_{i,t} = CES\left(K_{i,t}; LD_{i,t}; \sigma^{KLD}\right) =$$

$$\alpha_i(a_i \cdot K_{i,t}{}^{\frac{\sigma^{KLD}-1}{\sigma^{KLD}}} + (1-a_i) \cdot LD_{i,t}{}^{\frac{\sigma^{KLD}-1}{\sigma^{KLD}}})^{\frac{\sigma^{KLD}}{\sigma^{KLD}-1}}, \forall(i = irri, t) \qquad \text{(Eq.2.7)}$$

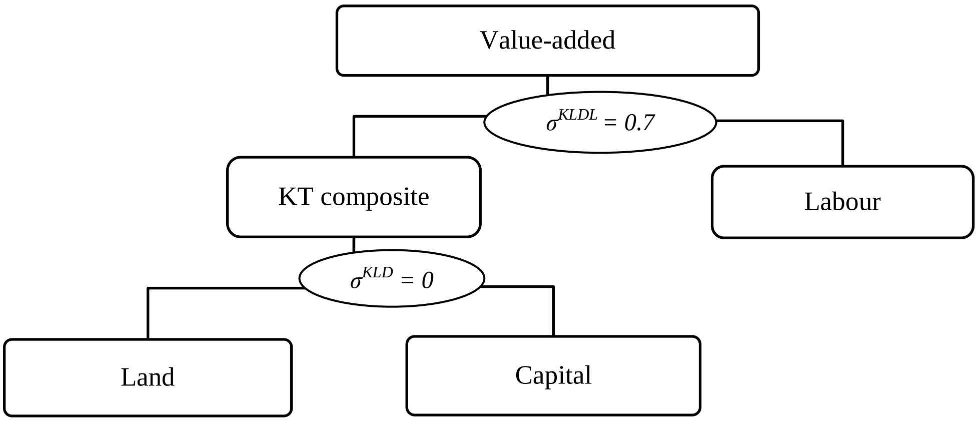
The equilibrium in the market for production factors is obtained from the following equation, where τ^{va} is value added tax, $Pva_{i,t}$ value added price, $P_{Tr,t}$ land price in irrigated agriculture sectors, $P_{k,t}$ capital price, $P_{L,t}$ labour price, $P_{wr,t}$ water price in irrigated agriculture sectors and τ^{wf} is the markup on the water factor that will be used in the economic policy simulations (see chapter 4).

$$(Pva_{i,t} + \tau^{va})\ \cdot qva_{i,} =$$

$$P_{k,t} \cdot K_{i,t} + P_{Tr,t} \cdot LD_{i,t} + P_{L,t} \cdot L_{i,t} + \left(P_{wr,t} + \tau^{wf}\right) \cdot W_{i,t}, \forall(i = irri, t) \qquad \text{(Eq.2.8)}$$

In the non-irrigated agriculture sector ($inirri$), which does not use the water factor, the value added production technology is represented in Figure 2.4.

Figure 2.4. **Value-added structure for non-irrigated agriculture sector**



Source: Own work.

The amount of value added is modeled through a CES function between labour ($L_{i,t}$) and the capital-land aggregate ($KLD_{i,t}$). The index $inirri$ refers to non-irrigated agriculture sectors.

$$qva_{i,t} = CES\left(L_{i,t}; KLD_{i,t}; \sigma^{KLDL}\right) = \alpha_i\left(a_i \cdot L_{i,t}^{\frac{\sigma^{KLDL}-1}{\sigma^{KLDL}}} + (1-a_i) \cdot KLD_{i,t}^{\frac{\sigma^{KLDL}-1}{\sigma^{KLDL}}}\right)^{\frac{\sigma^{KLDL}}{\sigma^{KLDL}-1}}, \forall(i = inirri, t) \tag{Eq.2.9}$$

In the following nested level, the aggregate $KLD_{i,t}$ combines land and capital in the same way as in irrigated agriculture sectors.

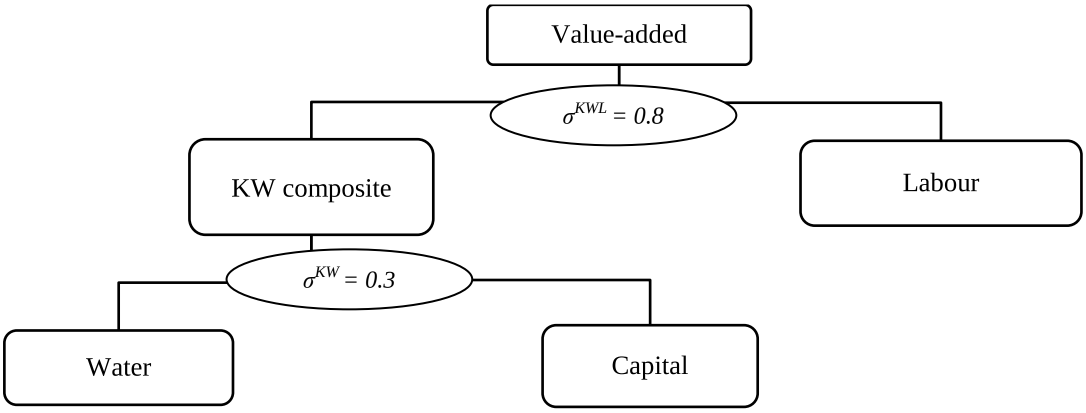
$$KLD_{i,t} = CES\left(K_{i,t}; LD_{i,t}; \sigma^{KLD}\right) = \alpha_i\left(a_i \cdot K_{i,t}^{\frac{\sigma^{KLD}-1}{\sigma^{KLD}}} + (1-a_i) \cdot LD_{i,t}^{\frac{\sigma^{KLD}-1}{\sigma^{KLD}}}\right)^{\frac{\sigma^{KLD}}{\sigma^{KLD}-1}}, \forall(i = inirri, t) \tag{Eq.2.10}$$

The equilibrium in the production factors market for non-irrigated agriculture sector differs from the equilibrium in irrigated agriculture sectors due to land factor price being different between irrigated agriculture sectors ($P_{Tr,t}$) and non-irrigated agriculture sector ($P_{T,t}$).

$$(Pva_{i,t} + \tau^{va}) \cdot qva_{i,t} = P_{k,t} \cdot K_{i,t} + P_{T,t} \cdot LD_{i,t} + P_{L,t} \cdot L_{i,t}, \forall (i = inirri, t) \quad \text{(Eq.2.11)}$$

Finally, the value added production technology for other sectors ($ires$) which do not use water but do use the land factor is represented in Figure 2.5.

Figure 2.5. **Value-added structure for rest of sectors**



Source: Own work.

The amount of value added is modelled through a CES function between labour ($L_{i,t}$), and the capital-water aggregate ($KW_{i,t}$). The elasticity of substitution between the $KW_{i,t}$ aggregate and labour factor (σ^{KWL}) follows the value obtained in Seung *et al.* (1998 [170]).

$$qva_{i,t} = CES(L_{i,t}; KW_{i,t}; \sigma^{KWL}) =$$

$$\alpha_i (a_i \cdot L_{i,t}^{\frac{\sigma^{KWL}-1}{\sigma^{KWL}}} + (1 - a_i) \cdot KW_{i,t}^{\frac{\sigma^{KWL}-1}{\sigma^{KWL}}})^{\frac{\sigma^{KWL}}{\sigma^{KWL}-1}}, \forall (i = ires, t) \quad \text{(Eq.2.12)}$$

Aggregate $KW_{i,t}$ is again modelled through a CES function between the water factor ($W_{i,t}$) and the capital factor ($K_{i,t}$).

$$KW_{i,t} = CES(K_{i,t}; W_{i,t}; \sigma^{KW}) =$$

$$\alpha_i (a_i \cdot K_{i,t}^{\frac{\sigma^{KW}-1}{\sigma^{KW}}} + (1 - a_i) \cdot W_{i,t}^{\frac{\sigma^{KW}-1}{\sigma^{KW}}})^{\frac{\sigma^{KW}}{\sigma^{KW}-1}}, \forall (i = ires, t) \quad \text{(Eq.2.13)}$$

The following equation determines the equilibrium in the production factors market.

$$(Pva_{i,t} + \tau^{va}) \cdot qva_{i,t} =$$

$$P_{k,t} \cdot K_{i,t} + P_{L,t} \cdot L_{i,t} + \left(P_{w,t} + \tau^{wf}\right) \cdot W_{i,t}, \forall (i = ires, t) \qquad \text{(Eq.2.14)}$$

2.4.2. The representative agent

There are two consumer groups: a representative agent and the government. The representative agent maximises the total utility subject to the budgetary constraint (total expense cannot be upper than income). Incomes come from the sale of their factor endowments and direct transfers from the government and foreign sector, which are spent on consumption ($C_{i,t}$), tax payments (τ^d), savings (S_t) and transfers to the rest of the world ($trnsf_t$), that are the remaining balance of the difference between transfers received and paid.

$$P_{k,t} \cdot K_{i,t} + P_{T,t} \cdot LD_{inirri,t} + P_{Tr,t} \cdot LD_{irri,t} + w_{L,t} \cdot L_{i,t} + (1 - \tau^{wf}) \cdot P_{w,t} \cdot W_{ires,t}$$

$$+ (1 - \tau^{wf}) \cdot P_{wr,t} \cdot W_{irri,t} + trnsf_t - \tau^d = PQ_{i,t} \cdot C_{i,t} + S_t, \forall\ (i, t) \qquad \text{(Eq.2.15)}$$

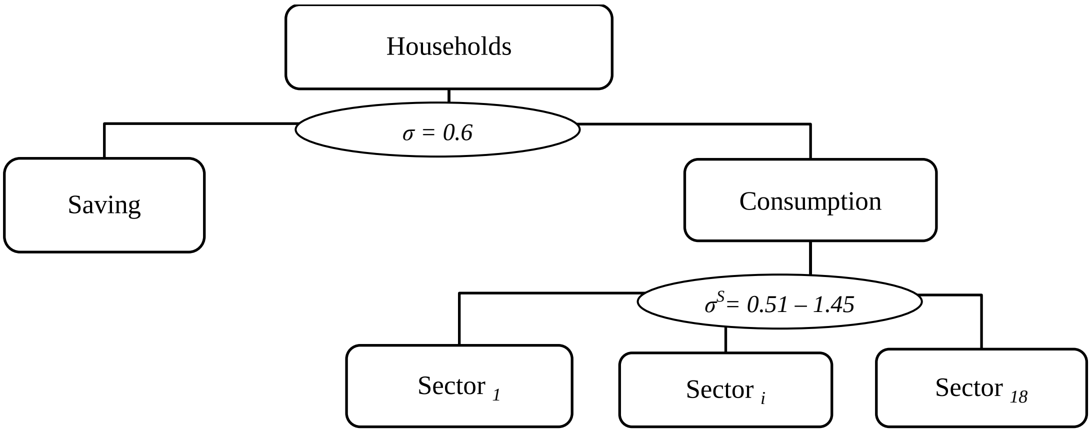
Figure 2.6 shows the consumption nesting structure of the representative agent. The representative agent decides the basket of goods through utility functions, whose nesting structures are shown in Figure 2.6 and equations 2.16 and 2.17, and whose demand elasticities are presented in Table 2.2.

$$U_t = f(C_t; S_t; \sigma^U; \sigma), \forall (i, t) \qquad \text{(Eq.2.16)}$$

$$C_t = CES\left(C_{1,t}, C_{2,t}, \dots, C_{i,t}; \varphi; \sigma^s\right) =$$

$$\alpha\left(a_1 \cdot C_{1,t}^{\frac{\sigma^s-1}{\sigma^s}} + a_2 \cdot C_{2,t}^{\frac{\sigma^s-1}{\sigma^s}} + a_3 \cdot C_{3,t}^{\frac{\sigma^s-1}{\sigma^s}} +_{\dots} + a_i \cdot C_{i,t}^{\frac{\sigma^s-1}{\sigma^s}} \right)^{\frac{\sigma^s}{\sigma^s-1}} \qquad \text{(Eq.2.17)}$$

Figure 2.6. **Consumption nesting structure**



Source: Own work.

Table 2.2. **Demand elasticities by sector σ^S**

Irrigated agriculture	0.83	Minerals and metals	1.45	Manufactures	1.29
Non-irrigated agriculture	0.83	Minerals and non-metals products	0.51	Rubber, plastics and others	1.31
Livestock	0.92	Chemicals	1	Construction and engineering	0.75
Energy products	0.56	Metal products machinery and transport material	1.45	Hotels and restaurants	1.7
Water utilities	0.71	Agri-food industry	0.83	Other services	0.96

Source: All demand elasticity coefficients are taken from Mainar (2010 [115]), except for Livestock, which is taken from Radwan *et al*. (2009 [149]).

2.4.3. Government

Government receives taxes from the representative agent, value added tax, and taxes and transfers from the rest of the world. It spends them on consumption, savings and transfers to the representative agent. Total public expenditure is modelled through a fixed coefficients structure. The lump-sum transfers between the representative agent and Government are endogenously adjusted to ensure a balanced budget. This ensures the same budget balance for Government as in the baseline.

The budget balance is regulated by:

$$Pva_{i,t} \cdot \tau^{va} \cdot qva_{i,t} + \tau^{d} = trnsf_{t} + PQ_{i,t} \cdot G_{i,t}, \forall (i,t) \qquad \text{(Eq.2.18)}$$

2.4.4. The foreign sector

Huesca's economy is considered too small to influence world prices, which are fixed. We also adopt an Armington (1969 [7]) approach, in which domestic and imported goods are imperfect substitutes. To do this, the Armington aggregate ($A_{i,t}$) is modelled through a CES function which aggregates domestic production and imported goods.

$$A_{i,t} = CES\left(Y_{i,t}^{D}, M_{i,t}; \sigma^{A}\right) = \beta_i \left(b_i \cdot Y_{i,t}^{D\,\frac{\sigma^{A}-1}{\sigma^{A}}} + (1-b_i) \cdot M_{i,t}^{\frac{\sigma^{A}-1}{\sigma^{A}}}\right)^{\frac{\sigma^{A}}{\sigma^{A}-1}}, \forall (i,t) \qquad \text{(Eq.2.19)}$$

Output destination is modelled with a constant elasticity of transformation function (CET), which allows the output earmarked by each sector to supply domestic demand ($Y_{i,t}^{D}$), and foreign demand via exports ($E_{i,t}$). Therefore, CET elasticity shows substitutability between supply intended for the domestic market and foreign market.

$$YT_{i,t} = CET\left(Y_{i,t}^{D}, E_{i,t}; \Omega^{E}\right) = \gamma_i \left(c_i \cdot Y_{i,t}^{D\,\frac{\Omega^{E}-1}{\Omega^{E}}} + (1-c_i) \cdot E_{i,t}^{\frac{\Omega^{E}-1}{\Omega^{E}}}\right)^{\frac{\Omega^{E}}{\Omega^{E}-1}}, \forall (i,t) \qquad \text{(Eq.2.20)}$$

Under these assumptions, the rest of the world is divided into three agents: rest of Spain, rest of the European Union (EU) and all other countries treated as a single region (row). The exchange rate between the province of Huesca, the rest of Spain and the European Union ($\overline{PFX_t}$) remains equal to the *numeraire*, while the trade balance adjusts, as the province of Huesca trades in euros. However, the trade balance between these three regions and other countries is held constant ($\overline{XS_t}$)and it is the exchange rate which adjusts.

$$\sum_{i=1}^{I} \overline{PFX_t}\left(X_{i,t} - M_{i,t}\right) = XS_t, \forall (i = rest\ of\ Spain\ and\ EU, t) \qquad \text{(Eq.2.21)}$$

$$\sum_{row}^{l} PFX_t \left(X_{row,t} - M_{row,t}\right) = \overline{XS_t}, \forall(row,t) \qquad \text{(Eq.2.22)}$$

As explained in Robinson (2006 [154]), the exchange rate included in computable general equilibrium models defines units of domestic currency per unit of foreign currency, where the "currency" is not money but simply defines the units of domestic and world prices, i.e. domestic prices in local currency units and world prices in foreign currency units (e.g. dollars).

The value of elasticities Armington (σ^A) and CET (Ω^E) are shown in Table 2.3 by sectors.

Table 2.3. **Armington and CET elasticities**

Sectors	σ^A	Ω^E	Sectors	σ^A	Ω^E	Sectors	σ^A	Ω^E
Irrigated agriculture	2.3	3.9	Minerals and metals	2.8	2.9	Manufactures	2.2	2.9
Non-irrigated agriculture	2.3	3.9	Minerals and non-metals products	3	2.9	Rubber, plastics and others	2.8	2.9
Livestock	2.3	3.9	Chemicals	1.9	2.9	Construction and engineering	1.9	0.7
Energy products	2.8	2.9	Metal products machinery and transport material	2.8	2.9	Hotels and restaurants	1.9	0.7
Water utilities	2.8	2.9	Agri-food industry	2.2	2.9	Other services	1.9	0.7

Source: Hertel (1997 [93]) and De Melo and Tarr (1992 [53]).

2.4.5. Farmer: An additional agent

As explained in detail in chapter 4, the aim of the proposed strategies is to foster the efficient use of natural resources in irrigated agriculture sectors in order to mitigate the economic effects of reducing the volume of water available for irrigation. Improving the efficiency of water use requires an additional cost in respect of irrigation modernisation. Therefore, a percentage of the cost of water factor or markup is used to finance these efficiency gains in our simulations.

The additional agent, *Farmer*, collects and allocates this markup on the cost of water to investment in modernisation and technological change only in irrigated agriculture sectors. In other words, this agent works as a neutral organisation responsible for the revenue collection and investment process. Similar functions are carried out in the region by the Upper Aragon Irrigation Scheme and the Ebro Water Board (CHE). The equilibrium of this agent is determined by the following equation, where $P_{wr,t}$ is the price of the water factor in irrigated agriculture sectors, $P_{w,t}$ is the price of the water factor in other sectors and τ^{wf} is the markup factor applied to water used in simulations of economic policy. Depending on the scenario in question, the revenues collected are earmarked for investment or spending on intermediate inputs.

$$P_{w,t} \cdot W_{ires,t} \cdot \tau^{wf} + P_{wr,t} \cdot W_{irri,t} \cdot \tau^{wf} = \sum_{i=1}^{I} P_{i,t} \cdot I_{i,t} + PQ_{i,t} \cdot Y_{i,t}^{ID}, \forall(i,t) \qquad \text{(Eq.2.23)}$$

2.4.6. Savings and investment

Finally, the savings-investment account closes the model with the aggregation of savings from the alternative agents and their allocation to domestic investment. To balance savings and investment in the case of a closed economy, the value of total investment can be set in the model so that the balance determines saving. This is known as investment-driven or Johansen closure. An alternative is to fix the value of savings and let the balance determine total investment in what is called savings-driven or neoclassical closure.

In an open economy like that considered here, however, the difference between savings and investment must be equal to the difference in payments to the foreign sector. In to close an open economy model, then, we must determine two of three elements (saving, investment and balance of payments with the foreign sector). As explained above, the trade balance with the rest of Spain and the European Union is treated under the condition of a fixed exchange rate. Therefore, saving and investment are determined.[26]

$$\overline{S_t} - \sum_{i=1}^{I} P_{i,t} \cdot \overline{I_{\iota,t}} = XS_t, \forall(i,t) \qquad \text{(Eq.2.24)}$$

---

[26] Note that the trade balance between the three regions and the rest of the world is fixed.

2.4.7. Model dynamic

2.4.7.1. Recursive dynamic

The recursive dynamic model described in chapter 4 was specified following Paltsev (2000 [139]). The labour supply grows at a constant rate. The index g refers to growth rate.

$$\overline{L_{t+1}} = \overline{L_t}(1+g) \qquad \text{(Eq.2.25)}$$

The evolution of capital is given by equation 2.26. The index δ refers to depreciation rate.

$$K_{t+1} = K_t(1-\delta) + I_t \qquad \text{(Eq.2.26)}$$

We also assume that capital grows at the same constant rate.

$$K_{t+1} = K_t(1+g) \qquad \text{(Eq.2.27)}$$

The combination of the above equations allows us to obtain the following equation:

$$I_t = K_t(g+\delta) \qquad \text{(Eq.2.28)}$$

The relationship between the initial value of capital endowment in the economy (KD_t), the rental price of capital or rate at which capital is rent (RK_t)[27] and a stock of capital (K_t) is as follows:

$$KD_t = RK_t * K_t \qquad \text{(Eq.2.29)}$$

We assume a constant rate of interest (r) so that all future prices will be in present value:

$$P_{t+1} = \frac{P_t}{1+r} \qquad \text{(Eq.2.30)}$$

---

[27] Note that the purchase price and the rental price of capital are different. The SAM reports the payments to capital in the base period. Following Harberger's convention, a unit price and an amount of capital equal to the value of the income received in the base period may be chosen.

If we consider the first-order conditions for capital and investment [28]:

$$PK_t = (1-\delta)PK_{t+1} + RK_t \qquad \text{(Eq.2.31)}$$

$$PK_{t+1} = P_t \qquad \text{(Eq.2.32)}$$

Therefore, using equation 2.30 and substitution equations 2.31 and 2.32, we obtain:

$$RK_t = (\delta + r)P_t \qquad \text{(Eq.2.33)}$$

Finally, taking into account equations 2.28, 2.29 and 2.33 investment in the calibration period, assuming $P_0 = 1$, is

$$I_0 = \frac{(g+\delta)}{(\delta+r)} * KD_0 \qquad \text{(Eq.2.34)}$$

2.4.7.2. Intertemporal dynamic

One of the key differences between a recursive dynamic model and a model with intertemporal dynamic lies in the expectations of agents. In a recursive model, decisions on production, consumption and investment are taken following prices in the decision period. In an intertemporal model, however, decisions on production, consumption and investment are based on the rational expectations of agents over an infinite horizon or longer. In other words, economic agents know exactly what will happen in the future in all periods covered by the model (for more details see Babiker *et al*., 2009 [12]).

The fourth chapter focuses on a specific time by analysing the effects of the evolution of water resources throughout this period, so we adopt a recursive dynamic model. However, the fifth chapter includes stochastic elements in the model, so we have chosen an intertemporal dynamic because our simulations are not based on a specific period of time and we want to evaluate the influence of uncertainty. In this case, an important characteristic of the dynamic problem is the treatment of capital in the last

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[28] These conditions are obtained by solving the problem of utility maximisation (see Paltsev, 2000 [139]).

period. Following Lau *et al*. (1997 [103]), we introduce the level of post-terminal capital as a variable and an additional constraint on the growth rate of investment in the terminal period, as follows:

$$\frac{I_T}{I_{T-1}} = \frac{Y_T}{Y_{T-1}}, \ \ \forall(t) \qquad \text{(Eq.2.35)}$$

where T is a terminal period. The meaning of this constraint is that investment in a terminal period should grow at the same rate as output. Therefore, it requires balanced growth in the terminal period, but does not require that the model achieve steady-state growth.

2.4.8. Technological change

Next, we examine the technological improvements implemented and explained in the fourth chapter in detail. These improvements in efficiency in the use of water and land resources are included in the model by incorporating technological change in irrigated agriculture sectors. Alternative technological changes are specified in four types.

I. The first is associated with the transformation of non-irrigated land into irrigated land even though total land area remains constant. This change has played an important role in Spain since the 1960s. Equation 2.1 presented above shows the μ_t parameter defined in equation 2.36, where $\overline{CL}$ is the cost of transforming non-irrigated into irrigated land obtained from Zubieta (2010 [189]) and Z_t is the amount collected to pay for modernisation. The amount collected by the *Farmer* agent is earmarked for investment in the "Construction and engineering" sector.

$$\mu_t = \frac{Z_t}{\overline{CL}} \qquad \text{Eq.(2.36)}$$

II. The next improvement is the change in the use of factors. For this, technological progress is included in the water factor production function through the water factor. Equation 2.6 incorporates technological change through the parameter φ_t. In the calibration scenario, this parameter is 1, but in case of an increase in water productivity it will be greater than 1, and if water productivity decreases it will be less than 1. The meaning of φ_t is that water is an effective resource. Thus, doubling the efficiency of use is the same as doubling the amount of water available. Moreover, if we reconsider Figure 2.3, water is a factor substitute for aggregate capital-land, for which the elasticity of substitution varies depending on the crop irrigation technique used. This implies that the technological changes associated with effective water are specified in two effects; on the one hand, the technological change of φ_t determined by investment in modernisation associated with Z_t as we have shown, and, on the other, internal substitution processes, since these factors are imperfect substitutes.

It is usually accepted, in line with historical experience of the processes of development in irrigation, that the efficiency factor φ_t follows a logistic evolution, which will be captured through a Gompertz function (equation 2.37). This function will represent an improvement in efficiency from a real initial value for 2002 (efficiency level of 54%) to an efficiency level of 60% in 2010 and a final upper asymptotic level of 90%. Specifically, the efficiency factor of φ_t will be defined by:

$$\varphi_t = a \cdot e^{(-e^{b-c\cdot\lambda_t\cdot t})} \text{ , } \forall(t) \qquad \text{(Eq.2.37)}$$

where a is equal to 0.90, as the assumed ceiling[29]; $b = \ln\left(-\ln\left(\frac{0.54}{0.90}\right)\right)$ and $c = \frac{\ln\left(-\ln\left(\frac{0.60}{0.90}\right)\right)-b}{-8}$. When $\lambda_t = 1$, a, b and c ensure the levels of efficiency of 54%, 60% and 90% respectively, commented above. Let us note that the parameter c of the Gompertz function is multiplied by the parameter λ_t defined in the following equation.

$$\lambda_t = \left(\frac{Z_t}{\overline{C}}\right)^{\gamma} \text{ ,} \forall(t) \text{ when } \gamma < 1, \lambda_0 = 1 \qquad \text{(Eq.2.38)}$$

This parameter depends on the sum (Z_t) collected by the *Farmer* and the annual initial cost of technology $\overline{C}$, which covers about €40 million, as we shall see in the next chapter. As γ is less than 1, meanwhile, we may assume that efficiency

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[29] We assume that the ceiling of the Gompertz function is equal to 90% due to water losses during transport and use, which are very difficult to prevent (see chapter 1).

gains increase more slowly than collection. In other words, twice the investment does not double the gain. In this case, the income obtained goes on higher energy expenditure and investment in “Construction and engineering”.

III. The next technological change is associated with learning in the use of land and crop patterns through efficiency improvements in the parameter of the CET function which models the allocation of land. The γ parameter of equation 2.1 is defined by equation 2.39, where $\bar{C}$ is the index cost of technology without considering the energy costs and Z_t is the amount collected. The initial value of 2% is an approximate value for average land productivity in the Upper Aragon region from 2002 to 2010 based on DGA (2009 [56], 2011b [58]). Incomes are spent on investing in “Construction and engineering”.

$$\gamma_t = 0.02 \text{ x } (1+\frac{Z_t}{\bar{C}}) \qquad \text{(Eq.2.39)}$$

IV. Finally, the last technological improvement models the productivity gains for irrigation as a whole. This shows the result of farmers’ reactions after the increase in costs and productivity gains which depend on multiple factors such as irrigation know-how, agricultural research and product marketing. This technological change is produced by variations in the α_i parameter (see equation 2.5). These productivity gains are also considered in the empirical application in the third chapter. In our simulation, we assume a fixed annual gain of 3.5%, which is the average level around which the overall productivity of irrigation in the region for the period 2002–2010 moves, based again on DGA (2009 [56], 2011b [58]). The revenues collected are used to invest in all sectors, because this payment is less specific.

2.4.9. Equilibrium and calibration

The market clearance condition requires that the demand for all goods and factors of production must be equal to their supply. In the following equations, we establish the market equilibrium in the goods and services markets and production factors (capital, labour, water and land) and the balance in the savings-investment account.

$$Y_{i,t}^{D} = \sum_{j=1}^{J} A_{j,t} + C_{i,t} + G_{i,t} + I_{i,t}, \forall(i,t) \qquad \text{(Eq.2.40)}$$

$$\overline{K_t} = \sum_{i=1}^{I} K_{i,t}, \forall(i,t) \qquad \text{(Eq.2.41)}$$

$$\overline{L_t} = \sum_{i=1}^{I} L_{i,t}, \forall(i,t) \qquad \text{(Eq.2.42)}$$

$$\overline{W_t} = \sum_{i=1}^{I} W_{i,t}, \forall(i,t) \qquad \text{(Eq.2.43)}$$

$$\overline{T_t} = \sum_{i=1}^{I} T_{i,t}, \forall(i,t) \qquad \text{(Eq.2.44)}$$

$$\sum_{i=1}^{I} \overline{PFX_t}\left(X_{i,t} - M_{i,t}\right) = XS_t, \forall(i = rest\ of\ Spain\ and\ UE, t) \qquad \text{(Eq.2.45)=(Eq.2.22)}$$

The market equilibrium conditions are satisfied by the adjustment of relative prices. Zero degree homogeneity is assumed for all supply and demand functions in the model. In line with the general equilibrium framework, only relative prices are relevant for the specification of the quantities of goods supplied and demanded. This requires determining a *numeraire* price in the model. The consumer price index (CPI) is used as the *numeraire* price level against which all relative prices in the model are measured.

With regard to calibration, the elasticity parameters were selected on the basis of a review of the literature and studies in this area (Table 2.4). The values of the main dynamic model parameters were obtained from actual average data for the region in the period 2002–2010 (INE, 2002–2010 [98]). Specifically, the annual interest rate is 4.31% and the growth rate is 2.01%. The relationship between capital and investment in the steady-state is obtained from the calibration of the model using SAM data.

Table 2.4. **Elasticity parameters used in the model**

Elasticity of substitution between:	
Intermediate inputs and value-added	$\sigma^{Y} = 0$
Intermediate inputs	$\sigma^{I} = 0$
Irrigated and Non-irrigated agricultural production (a)	$\sigma^{RS} = 1$
Labour and KLDW aggregate	(b) $\sigma^{KLDWL} = 0.7$ (Farm sectors) (c) $\sigma^{KLDWL} = 0.8$
Water and KLD aggregate (d)	$\sigma^{KLDW} = 0.3$ $\sigma^{KLDW} = 0.2$ (Fruit and vegetables) $\sigma^{KLDW} = 0.1$ (Olives and vineyards)
Capital and land (e)	$\sigma^{KLD} = 0.3$
Domestic and import goods (f)	$\sigma^{A} = 1.9 - 3$
Demand elasticity coefficients (g)	$\sigma^{C} = 0.51\text{-}1.45$
Elasticity of transformation between:	
Exports and domestic goods (h)	$\Omega^{E} = 0.7 - 3.9$
Land (i)	$\Omega^{1,2} = 0.1$ and 0.3

(a) Land and climate characteristics and differences in farming techniques mean that final goods produced by irrigated and non-irrigated agriculture are considered imperfect substitutes, following Gómez *et al*. (2004 [85]).

(b) The substitution between aggregate KLDW and labour is lower in the Farm sector due to the relevance of aggregate KLDW (Jomini *et al*., 1991 [100]).

(c) Seung *et al*. (1998 [170]).

(d) The substitution elasticity between capital and water is assumed to be 0.3 in all sectors. In the case of Irrigated agriculture, this value is the same in Cereals and industrial crops because they use sprinkler irrigation. However, the substitution elasticity is 0.2 in Fruit and vegetables and 0.1 in Olives and vineyards, because they use drip irrigation (see Gómez *et al*., 2004 [85]).

(e) Gómez *et al*. (2004 [85]).

(f) Hertel (1997 [93]).

(g) All sector demand elasticity coefficients are taken from Mainar (2010 [115]).

(h) De Melo and Tarr (1992 [53]).

(i) OECD (2003[135]).

2.5. Appendix B: Supplements to Chapter 2

This section contains three sections that supplement chapter 2. First, we explain the resolution of a sample model with a mixed complementarity problem. We also show the programming codes. We then go on to present the main elements (parameters, variables, equations) of the static model specified in chapter 3. Finally, we summarise the parameters and variables of the dynamic model described in this chapter and considered in chapter 4.

2.5.1. A mixed complementarity problem

2.5.1.1. MPSGE: A simple example

Let us consider a simple example of the MPSGE model comprising two sectors (*x*, *y*), one consumer (CONS) and two factors (L,K):

	Sectors		**CONS**	
Markets	**X**	**Y**	**W**	**CONS**
P_X	100		-100	
P_Y		100	-100	
P_W			200	-200
P_L	-40	-60		100
P_K	-60	-40		100

The total production of sector X is 100 units, which require the purchase of 40 units of labour and 60 units of capital. The production function assumes Cobb-Douglas elasticity of substitution. Meanwhile, the total output of sector Y is 100 units, requiring the purchase of 60 units of labour and 40 units of capital. The end consumer receives the total factor endowments, consisting of 100 units of labour and 100 units of capital, making a basket of goods equal to 200 units. This total budget allows consumers to buy a basket of goods of 100 units of X and 100 units of sector Y with a total 200 units of welfare (W).

1. Zero profit conditions: In this simple example, maximising profits associated with the Cobb-Douglas function ($K^{\alpha} * L^{(1-\alpha)}$) is equivalent to obtaining cost functions in MCP, taking into account that the value of intermediate inputs must be equal to or greater than output with the actual production costs.

Unit cost function to obtain X:

$$C_x(P_L, P_K) \geq P_X \rightarrow 100 * P_L^{0.4} * P_K^{0.6} \geq 100 * P_X$$

Unit cost function to obtain Y:

$$C_y(P_L, P_K) \geq P_Y \rightarrow 100 * P_L^{0.6} * P_K^{0.4} \geq 100 * P_Y$$

Unit expenditure function to obtain W:

$$e(P_X, P_Y) \geq P_W \rightarrow 200 * P_X^{0.5} * P_Y^{0.5} \geq 200 * P_W$$

2. Market clearance conditions: The price of production goods is determined as the balance between supply and demand for goods, while the price of the factors of production is determined as the balance between supply and demand factors.

To find P_X: $X \geq e_{P_X}(P_X, P_Y)W \rightarrow 100 * X \geq 100 * W * P_X^{0.5} * P_Y^{0.5} \ / \ P_X$

To find P_Y: $Y \geq e_{P_Y}(P_X, P_Y)W \rightarrow 100 * Y \geq 100 * W * P_X^{0.5} * P_Y^{0.5} \ / \ P_Y$

To find P_W: $W \geq CONS/P_W \rightarrow 200 * W = CONS \ / P_W$

To find P_L: $L \geq cxP_LX + cyP_LY \rightarrow$

$$100 \geq 40 * X * P_L^{0.4} * P_K^{0.6}/P_L + 60 * Y * P_L^{0.6} * P_K^{0.4}/P_L$$

To find P_K: $K \geq cxP_KX + cyP_KY \rightarrow$

$$100 \geq 60 * X * P_L^{0.4} * P_K^{0.6}/P_K + 40 * Y * P_L^{0.6} * P_K^{0.4}/P_K$$

3. Income balance conditions:

To find $CONS$: $CONS \geq P_LL + P_KK \rightarrow CONS = 100 * P_L + 100 * P_K$

A more detailed explanation of the different examples will be found in Philip (2009 [142]).

We present the solution with MCP programmed on a standard basis using GAMS, in subsection 2.6.5.2. By way of comparison, we present the solution of the same problem using the GAMS/MPSGE language used in this thesis for its plasticity and ease of programming in subsection 2.5.1.3. The comparison of both programming codes clearly reveals the advantages of the second language.

2.5.1.2. Programming code: A static model example solved with MCP

```
$TITLE Model- A static model example solved with MCP.

$ONTEXT

If we use the MCP format:

Production   Sectors      Consumers
 Markets  |   X      Y     W      | CONS
 -------------------------------------------------------
 PX       |  100            -100  |
 PY       |         100     -100  |
 PW       |                  200  | -200
 PL       |  -40    -60           | 100
 PK       |  -60    -40           | 100
 -------------------------------------------------------

$OFFTEXT
POSITIVE VARIABLES
 X
 Y
 W
 PX
 PY
 PW
 PL
 PK
 CONS;


EQUATIONS
 PRF_X    Zero profit for sector X
 PRF_Y    Zero profit for sector Y
 PRF_W    Zero profit for sector W
 MKT_X    Supply-demand balance for commodity X
 MKT_Y    Supply-demand balance for commodity Y
 MKT_L    Supply-demand balance for primary factor L
 MKT_K    Supply-demand balance for primary factor L
 MKT_W    Supply-demand balance for aggregate demand
 I_CONS   Income definition for CONS;


* Zero profit inequalities


PRF_X..  100 * PL**0.40 * PK**0.60 =G= 100*PX;

PRF_Y..  100 * PL**0.60 * PK**0.40 =G= 100*PY;

PRF_W..  200 * PX**0.5  * PY**0.5  =G= 200*PW;


* Market clearance inequalities

MKT_X.. 100 * X =G= 100 * W * PX**0.5 * PY**0.5 / PX;

MKT_Y.. 100 * Y =G= 100 * W * PX**0.5 * PY**0.5 / PY;

MKT_W.. 200 * W =E= CONS / PW;
```

```
MKT_L.. 100 =G= 40 * X * PL**0.40 * PK**0.60 / PL +
 60 * Y * PL**0.60 * PK**0.40 / PL;
MKT_K.. 100 =G= 60 * X * PL**0.40 * PK**0.60 / PK
+ 40 * Y * PL**0.60 * PK**0.40 / PK;

* Income balance equations
I_CONS.. CONS =E= 100* PL + 100*X*PL**0.25*PK**0.75;

MODEL ALGEBRAIC /PRF_X.X, PRF_Y.Y, PRF_W.W, MKT_X.PX, MKT_Y.PY,
MKT_L.PL, MKT_K.PK, MKT_W.PW, I_CONS.CONS /;

* Numeraire
PW.FX = 1;

* Set initial values of variables:
X.L=1; Y.L=1; W.L=1; PX.L=1; PY.L=1; PK.L=1; PL.L=1; CONS.L=200;

SOLVE ALGEBRAIC USING MCP;
```

Source: Own work following James R. Markusen´s guides (available on his website) [121].

2.5.1.3. Programming code: A static model example solved with MPSGE

```
$TITLE Model- A static model example solved with MPSGE.

$ONTEXT
If we use the MPSGE format:

Production   Sectors      Consumers
 Markets  |   X      Y     W      | CONS
 -------------------------------------------------------
 PX       |  100            -100  |
 PY       |         100     -100  |
 PW       |                  200  | -200
 PL       |  -40    -60           | 100
 PK       |  -60    -40           | 100
 -------------------------------------------------------
$OFFTEXT


$ONTEXT

$MODEL:Example1
$SECTORS:
X
Y
W


$COMMODITIES:
PX
PY
PL
PK
PW

$CONSUMERS:
CONS

$PROD:X   s:1
O:PX      Q:100
I:PL      Q:40
I:PK      Q:60


$PROD:Y   s:1
O:PY      Q:100
I:PL      Q:60
I:PK      Q:40
```

```
$PROD:W
O:PW      Q:200
I:PX      Q:100
I:PY      Q:100

$DEMAND:CONS
D:PW      Q:200
E:PL      Q:100
E:PK      Q:100

$OFFTEXT
$SYSINCLUDE mpsgeset Example1
* Numeraire
PW.FX = 1;

* Set initial values of variables:
X.L =1;Y.L=1; W.L=1; PX.L=1; PY.L=1; PK.L=1; PL.L=1; CONS.L=200;



$INCLUDE Example1.GEN
SOLVE Example1 USING MCP;
```

Source: Own work.

2.5.2. Domains, parameters, variables and equations of the static IFPRI model

Table B1. **Domains**

Symbol	Explanation	Symbol	Explanation
$a \in A$	*activities*	$c \in CD$	*commodities with domestic salesof domestic output*
$a \in ACES$	*activities with a CES function at the top of the technology nest*	$c \in CDN$	*commodities without domestic market sales of domestic output*
$a \in ALEO$	*activities with a Leontief function at the top of the technology nest*	$f \in F$	*factors*
$c \in C$	*commodities*	$h \in H$	*households*
$c \in CX$	*commodities with domestic output*	$i \in INS$	*institutions*
$c \in CM$	*imported commodities*	$i \in INSD$	*domestic institutions*
$c \in CE$	*exported commodities*	$i \in INSDNG$	*domestic nongovernment institutions*

Source: Löfgren *et al*. (2002 [111]).

Table B2. **Parameters**

Symbol	Explanation	Symbol	Explanation
iva_a	*quantity of value-added per activity unit*	$cwts$	*weight of commodity c in the CPI*
$ica_{c,a}$	*quantity of c per unit of aggregate intermediate input a*	$dwts$	*weight of commodity c in the producer price index*
$ice_{c,c'}$	*quantity of commodity c as trade input per exported unit of c.*	$shii_{i,i'}$	*share of net income among institutions*
$icd_{c,c'}$	*quantity of commodity c as trade input per unit of c produced and sold domestically*	$shif_{i,f}$	*share for domestic institution i in income of factor f*
$icm_{c,c'}$	*quantity of commodity c as trade input per imported unit of c*	tva_a	*rate of value-added tax for activity a*
$inta_a$	*quantity of aggregate intermediate input per activity unit*	ta_a	*tax rate for activity a*
$\overline{tins}_i$	*exogenous direct tax rate for domestic institution i*	te_c	*export tariff rate*
$tins01_i$	*1 for institutions with potentially flexed direct tax rates*	tq_c	*rate of sales tax*
$qdst$	*quantity of stock change*	tm_c	*import tariff rate*
$\overline{mps}_i$	*base savings rate for domestic institution i*	tf_f	*direct tax rate for factor f*
$mps01_c$	*1 for institutions with potentially flexed direct tax rates*	$trnsfr_{i,ac}$	*transfer from factor f to institution i*

$\overline{qinv}_c$	*base-year quantity of private investment demand*	$\overline{qg}_c$	*base-year quantity of government demand*
α_a^a	*efficiency parameter in the CES activity function*	ρ_a^a	*CES activity function exponent*
α_c^t	*CET function shift parameter*	ρ_c^t	*CET function exponent*
α_c^{ac}	*shift parameter for domestic commodity aggregation function*	ρ_c^{ac}	*domestic commodity aggregation function exponent*
α_a^{va}	*efficiency parameter in the CES value-added function*	ρ_a^{va}	*CES value-added function exponent*
α_c^q	*Armington function shift parameter*	ρ_c^q	*Armington function exponent*
δ_c^q	*Armington function share parameter*	$\theta_{a,c}$	*yield of output c per unit of activity a*
δ_a^a	*CES activity function share parameter*	$\gamma_{a,c,h}^h$	*subsistence consumption of home commodity c from activity a for household h*
δ_c^t	*CET function share parameter*	$\gamma_{c,h}^m$	*subsistence consumption of marketed commodity c for household h*
δ_{fa}^{va}	*CES value-added function share parameter for factor f in activity a*	$\beta_{a,c,h}^h$	*marginal share of consumption spending on home commodity c from activity a for household h*
$\delta_{a,c}^{ac}$	*share parameter for domestic commodity aggregation function*	$\beta_{c,h}^m$	*marginal share of consumption spending on marketed commodity c for household h*

Source: Löfgren *et al*. (2002 [111]).

Table B3. **Variables**

Exogenous			
$\overline{CPI}$	*consumer price index*	$\overline{EXR}$	*exchange rate*
$\overline{DTINS}$	*change in domestic institution tax share*	$\overline{PWE}_c$	*export price in foreign-currency units*
$\overline{GADJ}$	*government consumption adjustment factor*	$\overline{PWM}_c$	*import price in foreign-currency units*
$\overline{TINSADJ}$	*direct tax scaling factor*	$\overline{QFS}_f$	*quantity supplied of factor*
$\overline{IADJ}$	*investment adjustment factor*	$\overline{WFDIST}_{fa}$	*wage distortion factor for factor f in activity a*
$\overline{MPSADJ}$	*savings rate scaling factor*		
Endogenous			
PX_c	*aggregate producer price for commodity*	QX_c	*aggregate marketed quantity of domestic output of commodity*
PA_a	*activity price*	QA_a	*quantity (level) of activity*

PQ_c	*composite commodity price*	QQ_c	*quantity of goods supplied to domestic market*
PVA_a	*price of value-added*	QVA_a	*quantity of (aggregate) value-added*
PM_c	*import price*	QM_c	*quantity of imports of commodity*
PE_c	*export price*	QE_c	*quantity of exports*
$PINTA_a$	*aggregate intermediate input price for activity a*	$QINTA_{c,a}$	*quantity of aggregate intermediate input*
$PXAC_{ac}$	*producer price of commodity c for activity a*	$QXAC_{ac}$	*quantity of marketed output of commodity c from activity a*
PDD_c	*demand price for commodity produced and sold domestically*	QD_c	*quantity sold domestically of domestic output*
PDS_c	*supply price for commodity produced and sold domestically*	$QINV_c$	*quantity of investment demand for commodity*
EH_h	*consumption spending for household*	$TRII_{ii''}$	*transfers amonginstitutions*
EG	*government expenditures*	QF_{fa}	*quantity demanded of factor f from activity a*
$GSAV$	*government savings*	$QINT_a$	*quantity of commodity c as intermediate input to activity a*
$FSAV$	*foreign savings*	QG_c	*government consumption demand for commodity*
$INVSHR$	*investment share in nominal absorption*	QH_{ch}	*quantity consumed of commodity c by household h*
$GOVSHR$	*government consumption share in nominal absorption*	QHA_{ach}	*quantity of household home consumption of commodity c from activity a for household h*
MPS_i	*marginal propensity to save for domestic nongovernment institution*	YG	*government revenue*
$DMPS$	*change in domestic institution savings rates*	YIF_{if}	*income to domestic institution from factor*
DPI	*producer price index for domestically marketed output*	YI_i	*income of domestic nongovernment institution*
$TINS_i$	*direct tax rate for institutions*	YF_f	*income of factor*
$TABS$	*total nominal absorption*	WF_f	*average price of factor f*

Source: Löfgren *et al*. (2002 [111]).

Table B4. **Equations of the IFPRI model**

Production and Trade

$$QA_a = \alpha_a^a (\delta_a^a \cdot QVA_a^{-\rho_a^a} + (1-\delta_a^a) \cdot QINTA_a^{-\rho_a^a})^{-\frac{1}{\rho_a^a}} \tag*{Eq. B1}$$

$$\frac{QVA_a}{QINTA_a} = \left(\frac{PINTA_a}{PVA_a} \cdot \frac{\delta_a^a}{1-\delta_a^a} \right)^{\frac{1}{1+\rho_a^a}} \tag*{Eq. B2}$$

$$QVA_a = iva_a \cdot QA_a \tag*{Eq. B3}$$

$$QINTA_a = inta_a \cdot QA_a \tag*{Eq. B4}$$

$$QVA_a = \alpha_a^{va} \cdot \left(\sum_{f \in F} \delta_{f,a}^{va} \cdot QF_{f,a}^{-\rho_a^{va}} \right)^{-\frac{1}{\rho_a^{va}}} \tag*{Eq. B5}$$

$$WF_f \cdot \overline{WFDIST}_{f,a} = PVA_a (1 - tva_a) \cdot QVA_a \cdot \left(\sum_{f \in F'} \delta_{f,a}^{va} \cdot QF_{f,a}^{-\rho_a^{va}} \right)^{-1} \cdot \delta_{f,a}^{v,a} \cdot QF_{f,a}^{-\rho_a^{va}-1} \tag*{Eq. B6}$$

$$QINT_{c,a} = ica_{c,a} \cdot QINTA_a \tag*{Eq. B7}$$

$$QXAC_{a,c} + \sum_{h \in H} QHA_{a,c,h} = \theta_{a,c} \cdot QA_a \tag*{Eq. B8}$$

$$QX_c = \alpha_c^{ac} \cdot \left(\sum_{a \in A} \delta_{a,c}^{ac} \cdot QXAC_{a,c}^{-\rho_c^{ac}} \right)^{-\frac{1}{\rho_c^{ac}-1}} \tag*{Eq. B9}$$

$$PXAC_c = PX_c \cdot QX_c \left(\sum_{a \in A''} \delta_{a,c}^{ac} \cdot QXAC_{a,c}^{-\rho_c^{ac}} \right)^{-1} \cdot \delta_{a,c}^{ac} \cdot QXAC_{a,c}^{-\rho_c^{ac}-1} \tag*{Eq. B10}$$

$$QQ_c = \alpha_c^q \cdot (\delta_c^q \cdot QM_c^{-\rho_c^q} + (1-\delta_c^q) \cdot QD_c^{-\rho_c^q})^{-\frac{1}{\rho_c^q}} \tag*{Eq. B11}$$

$$\frac{QM_c}{QD_c} = \left(\frac{PDD_c}{PM_c} \cdot \frac{\delta_c^q}{1-\delta_c^q} \right)^{\frac{1}{1+\rho_c^q}} \tag*{Eq. B12}$$

$$QX_c = \alpha_c^t \cdot (\delta_c^t \cdot QE_c^{\rho_c^t} + (1-\delta_c^t) \cdot QD_c^{\rho_c^t})^{\frac{1}{\rho_c^t}} \tag*{Eq. B13}$$

$$QE_c = QD_c \left(\frac{PE_c}{PDS_c} \cdot \frac{1-\delta_c^t}{\delta_c^t} \right)^{\frac{1}{\rho_c^t - 1}} \tag*{Eq. B14}$$

Prices

$$PQ_c (1 - tq_c) QQ_c = PDD_c QD_c + PM_c QM_c \tag*{Eq. B15}$$

$$PX_c QX_c = PDS_c QD_c + PE_c QE_c \tag*{Eq. B16}$$

$$PA_a = \sum_c \theta_{a,c} PXAC_{ac} \tag*{Eq. B17}$$

$$PVA_a \cdot QVA_a = PA_a \cdot (1 - ta_a) \cdot QA_a - PINTA_a \cdot QINTA_a \tag*{Eq. B18}$$

$$PM_c = pwm_c(1+tm_c)\overline{EXR} + \sum_{c'} PQ_{c'} \cdot icm_{c'c} \qquad \text{Eq. B19}$$

$$PE_c = pwe_c(1-te_c)\overline{EXR} - \sum_{c'} PQ_{c'} \cdot ice_{c'c} \qquad \text{Eq. B20}$$

$$PINTA_a = \sum_{c} PQ_c \cdot ica_{c,a} \qquad \text{Eq. B21}$$

$$PDD_c = PDS_c + \sum_{c'\in CT} PQ_c \cdot icd_{c'c} \qquad \text{Eq. B22}$$

$$\overline{CPI} = \sum_{c} PQ_c \cdot cwts_c \qquad \text{Eq. B23}$$

$$DPI = \sum_{c} PDS_c \cdot dwts_c \qquad \text{Eq. B24}$$

Institutions

$$YF_f = \sum_{a\in A} WF_f \cdot \overline{WFDIST}_{f,a} \cdot QF_{f,a} \qquad \text{Eq. B25}$$

$$YF_{i,f} = shift_{i,f} \cdot \left[\left(1-tf_f\right)\cdot YF_f - trnsfr_{row,f} \cdot \overline{EXR}\right] \qquad \text{Eq. B26}$$

$$EH_h = \left(1 - \sum_{i\in INSDNG} shii_{i,h}\right)\cdot\left(1-MPS_h\right)\cdot\left(1-TINS_h\right)\cdot YI_h \qquad \text{Eq. B27}$$

$$QINV_c = \overline{IADJ} \cdot \overline{qinv_c} \qquad \text{Eq. B28}$$

$$PQ_c \cdot QH_{c,h} = PQ_c \cdot \gamma^{m}_{c,h} + \beta^{m}_{c,h} \cdot \left(EH_h - \sum_{c'\in C} PQ_{c'} \cdot \gamma^{m}_{c',h} - \sum_{a\in A}\sum_{c'\in C} PXAC_{a,c'} \cdot \gamma^{h}_{a,c',h}\right) \qquad \text{Eq. B29}$$

$$PXAC_c \cdot QHA_{a,c,h} = PXAC_{a,c} \cdot \gamma^{h}_{a,c,h} + \beta^{h}_{a,c,h} \cdot \left(EH_h - \sum_{c'\in C} PQ_{c'} \cdot \lambda^{m}_{c'h} - \sum_{a\in A}\sum_{c'\in C} PXAC_{a,c'} \cdot \gamma^{h}_{a,c',h}\right) \qquad \text{Eq. B30}$$

$$\begin{aligned} YG = {} & \sum_{i\in INSDNG} TINS_i \cdot YI_i + \sum_{f\in F} tf_f \cdot YF_f + \sum_{a\in A} tva_a \cdot PVA_a \cdot QVA_a \\ & + \sum_{a\in A} ta_a \cdot PA_a \cdot QA_a + \sum_{c\in CM} tm_c \cdot pwm_c \cdot QM_c \cdot \overline{EXR} + \sum_{c\in CE} te_c \cdot pwe_c \cdot QE_c \cdot \overline{EXR} \\ & + \sum_{c\in C} tq_c \cdot PQ_c \cdot QQ_c + \sum_{f\in F} YIF_{gov,f} + trnsfr_{gov,row} \cdot \overline{EXR} \end{aligned} \qquad \text{Eq. B31}$$

$$EG = \sum_{c\in C} PQ_c \cdot QG_c + \sum_{i\in INDNG} trnsfr_{i,gov} \cdot \overline{CPI} \qquad \text{Eq. B32}$$

$$YI_i = \sum_{f\in F} YIF_{i,f} + \sum_{i'\in INDNG'} TRII_{ii'} + trnsfr_{i,gov} \cdot \overline{CPI} + trnsfr_{i,row} \cdot \overline{EXR} \qquad \text{Eq. B33}$$

$$TRII_{ii'} = shii_{ii'} \cdot \left(1-MPS_{i'}\right)\cdot\left(1-TINS_{i'}\right)\cdot YI_{i'} \qquad \text{Eq. B34}$$

Equilibrium conditions

$$\sum_{a\in A} QF_{f,a} = \overline{QFS_f} \qquad \text{Eq. B35}$$

$$QQ_c = \sum_{a\in A} QINT_{c,a} + \sum_{h\in H} QH_{c,h} + QG_c + QINV_c + qdst_c + QT_c \qquad \text{Eq. B36}$$

$$\sum_{c\in CM} pwm_c \cdot QM_c + \sum_{f\in F} trnsfr_{row,f} = \sum_{c\in CE} pwe_c \cdot QE_c + \sum_{i\in INSD} trnsfr_{i,row} + FSAV \qquad \text{Eq. B37}$$

$$YG = EG + GSAV \qquad \text{Eq. B38}$$

$$TINS_i = \overline{tins_i} \cdot \left(1 + \overline{TINSADJ} \cdot tins01_i\right) + \overline{DTINS} \cdot tins01_i \qquad \text{Eq. B39}$$

$$MPS_i = \overline{mps_i} \cdot (1 - \overline{MPSADJ} \cdot mps01_i) + DMPS \cdot mps01_i \qquad \text{Eq. B40}$$

$$\sum_{i \in INSDNG} MPS_i \cdot (1 - TINS_i) \cdot YI_i + GSAV + \overline{EXR} \cdot FSAV = \sum_{c \in C} PQ_c \cdot QINV_c + \sum_{c \in C} PQ_c \cdot qdst_c \qquad \text{Eq. B41}$$

$$TABS = \sum_{h \in H} \sum_{c \in C} PQ_c \cdot QH_{c,h} + \sum_{a \in A} \sum_{c \in C} \sum_{h \in H} PXAC_{a,c} \cdot QHA_{a,c,h} + \sum_{c \in C} PQ_c \cdot QG_c$$
$$+ \sum_{c \in C} PQ_c \cdot QINV_c + \sum_{c \in C} PQ_c \cdot qdst_c \qquad \text{Eq. B42}$$

$$INVSHR \cdot TABS = \sum_{c \in C} PQ_c \cdot QINV_c + \sum_{c \in C} PQ_c \cdot qdst_c \qquad \text{Eq. B43}$$

$$GOVSHR \cdot TABS = \sum_{c \in C} PQ_c \cdot QG_c \qquad \text{Eq. B44}$$

Source: Löfgren *et al*. (2002 [111]).

2.5.3. List of indices, parameters and variables of the dynamic model

Table B5. **Dynamic model indices**

i, j, ii, I	Sectors and the total number of sectors
$irri$	Irrigated agriculture sector (*irri ϵ i*)
$inirri$	Non-irrigated agriculture sector (*inirri ϵ i*)
$ires$	Rest of sectors (*ires ϵ i*)
il	Sectors which use land factor (*il ϵ i*)
K, LD, W, L	Factors of production (capital, land, water, labor)
Wr, Tr	Water and land factors of Irrigated agriculture sectors
t	Set of time
f	Function
LT	Leontief function
CES	CES function
CET	CET function

Source: Own work.

Table B6. **Dynamic model variables**

$Y_{i,t}$	Production of sector *i*
$Y_{i,t}^{ID}$	Intermediate demand in sector *i*
$YT_{i,t}$	Total supply of good *i*
$A_{i,t}$	Total demand for good *i* (Armington function)
$qva_{i,t}$	Value-added of sector *i*
$Y_{i,t}^{D}$	Domestic demand for good *i*
$M_{i,t}; E_{i,t}$	Imports and exports of good *i*
XS_t	Surplus trade
$L_{i,t};K_{i,t};\ W_{i,t}; T_{i,t}$	Demand for labor, capital, water and land of sector *i*
$KLDW_{i,t}$	Water and capital-land composite
$KLD_{i,t}$	Capital and land composite
$KW_{i,t}$	Capital and water composite
$TR_{irri,t}$	Land supply of Irrigated Agriculture sectors
TNR_t	Land supply of Non-irrigated Agriculture sector
TT_t	Total supply of land
$C_{i,t};G_{i,t}$	Private and public consumption of good *i*
$I_{i,t}$	Investment in sector *i*
S_t	Savings
U_t	Utility of representative agent
WS_t	Water supply
$PT_{i,t}$	Equilibrium market price of goods for total production
$P_{i,t}$	Equilibrium market price of goods for the domestic market
$Pva_{i,t}$	Equilibrium market price of value-added aggregate
$PQ_{i,t}$	Equilibrium market price of composite commodity
$P_{k,t};P_{L,t};\ P_{w,t}; P_{T,t}$	Equilibrium market price of factors
$P_{wr,t};\ P_{Tr,t}$	Equilibrium market price of factors of irrigated agriculture sectors
$P_{I,t}$	Equilibrium market price of investment
PFX_t	Equilibrium exchange rate

Source: Own work.

Table B7. **Dynamic model parameters**

σ	Elasticity of substitution
Ω	Elasticity of transformation
g, δ, r	Growth, depreciation and interest rate
$\alpha_i, \beta_i, \gamma_i$	Efficiency parameter in production and consumption functions
a_l, a_i, b_i, c_i	Allocation parameter
$\varphi_t, \lambda_t, \gamma_t, \vartheta_t$	Level of water efficiency and scale exponent
Z_t	The amount collected
$\bar{C}$	Static cost index for technology = €40 million (see chapter 3)
$\overline{CL}$	Static cost for land transformation following Zubieta (2010 [189])
$trnsf_t$	Transferences among agents
τ^{va}, τ^{d}	Tax rate on value-added and directs taxes
τ^{wf}	Markup on water factor

Source: Own work.

Chapter 3

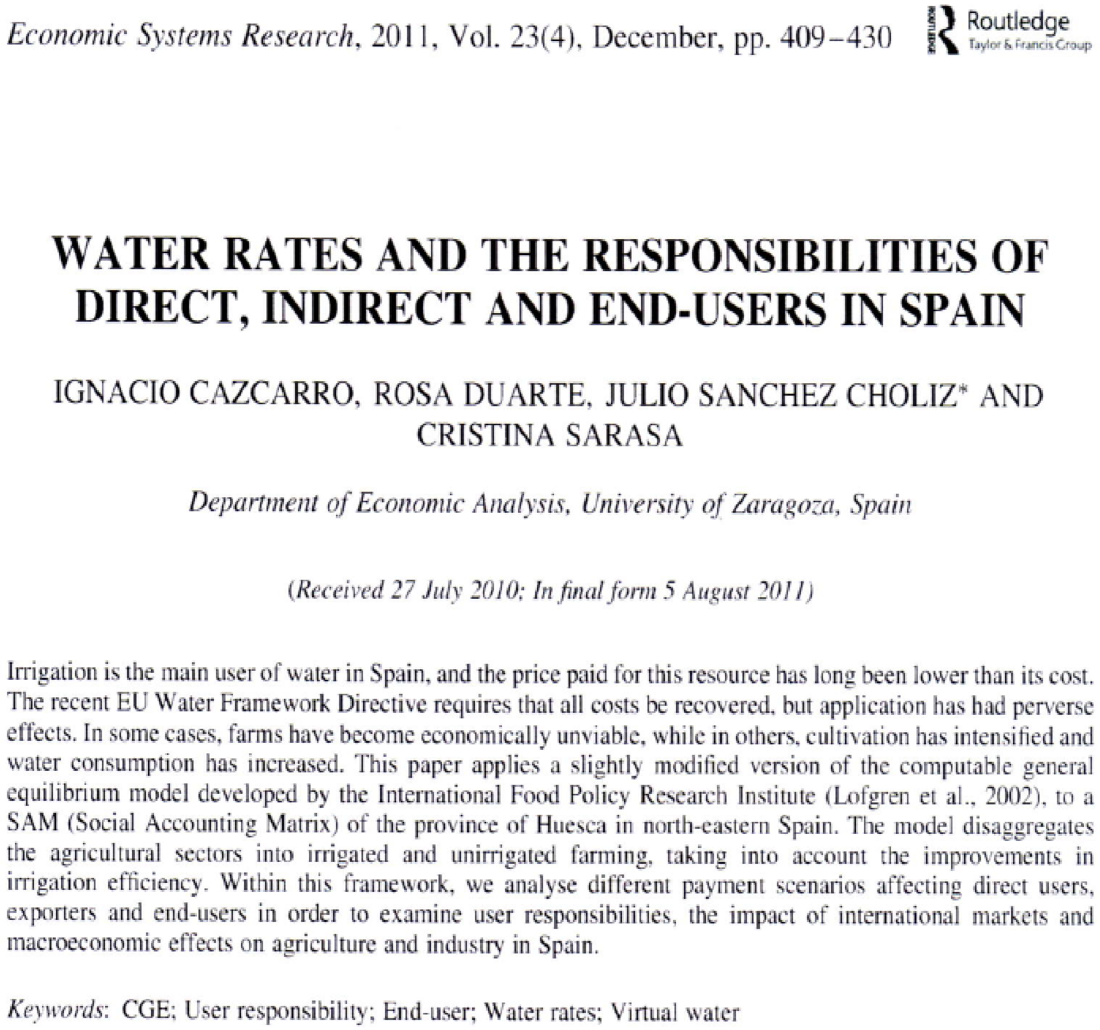
Effects of greater social responsibility in the use of water for irrigation

3.1. Presentation

Chapter 3 presents the paper published in *Economic Systems Research* (Cazcarro *et al*., 2011a [44]). This chapter addresses one of the guiding objectives of the thesis, the social co-responsibility in the use of water in the province of Huesca and the distribution of costs through the use of a static computable general equilibrium model. Therefore, after showing the irrigation water costs in the region and identifying the different kinds of users – direct, indirect and end-users – of the irrigation water, we analyse the effects of different kinds of distribution criteria for irrigation modernization costs. Starting from five payment scenarios, which have different payment criteria between direct users, exporters and end-users, we evaluate the responsibility of users, the impact on international markets and the macroeconomic effects on agriculture and industry in Spain.

The published work is presented in its original form. As in the first chapter, in order to harmonise the presentation of the thesis, small changes have been made to the presentation format. Tables and Figures keep their names, but we include the number of the chapter in the numbers of the Tables (e.g. 3.1, 3.2, 3.3…). In the same way, the paper’s references are included in the bibliography section of the thesis.

3.2. Water Rates and the Responsibilities of Direct, Indirect and End-Users



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WATER RATES AND THE RESPONSIBILITIES OF DIRECT, INDIRECT AND END-USERS IN SPAIN

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Irrigation is the main user of water in Spain, and the price paid for this resource has long been lower than its cost. The recent EU Water Framework Directive requires that all costs be recovered, but application has had perverse effects. In some cases, farms have become economically unviable, while in others, cultivation has intensified and water consumption has increased. This paper applies a slightly modified version of the computable general equilibrium model developed by the International Food Policy Research Institute (Lofgren et al., 2002), to a SAM (Social Accounting Matrix) of the province of Huesca in north-eastern Spain. The model disaggregates the agricultural sectors into irrigated and unirrigated farming, taking into account the improvements in irrigation efficiency. Within this framework, we analyse different payment scenarios affecting direct users, exporters and end-users in order to examine user responsibilities, the impact of international markets and macroeconomic effects on agriculture and industry in Spain.

Keywords: CGE; User responsibility; End-user; Water rates; Virtual water

3.2.1. Introduction

Water resources have been crucial to Spanish agriculture since Antiquity, as evidenced by the bronze plaques found at Contrebia Belaisca (near modern-day Botorrita in Aragon), which date from 89 BC and refer to the distribution of water between two communities. For centuries water was considered a communal (almost a *common*) good, and its use was regulated mainly by farmers themselves through local institutions, which also oversaw the construction and upkeep of the necessary infrastructure. This framework changed in the twentieth century. The expansion of irrigation and the creation of large scale irrigation systems intensified public intervention, with the result that water planning became a key tool for economic development. Investment in reservoirs and canals was initially financed by the state, and a large part of the costs were paid for by all citizens via taxation, and not just by farmers. So water became a productive input, a development that completely undermined the time-honoured local customs that had once governed use of the resource and the apportionment of costs. In addition, the increasing environmental impact of demand for irrigation water in the twentieth century, and the need to modernize and increase the efficiency of irrigation systems, have shifted the issues of costs and financing to the centre of debate. In this context, we address some of the issues raised by the intensification of water use in largely arid regions like Spain and its Mediterranean neighbours, Australia and certain parts of China.

The main response to these problems in Spain has been to treat water increasingly as an economic input, ignoring its other functions in the community, and to argue that all costs should be paid by direct users. This is the stance taken not only by the Spanish Water Act of 1985 but also by the EU Water Framework Directive (WFD [64]), which requires the recovery of all costs associated with water provision and obliges national governments to keep continental and maritime waters in pristine condition.

Most water use is, of course, associated with agriculture and, therefore, with the production of food for domestic consumption and export. In this light, it hardly seems fair that farmers should be the only ones required to pay for agricultural water use, as the benefits are shared by society as a whole (see Lenzen and Foran, 2001 [106]; and Lenzen and Peters, 2010 [109]). Perhaps, then, it would be more reasonable to spread the associated costs among all beneficiaries, including direct users such as farmers and hydroelectric utilities, indirect users, and end-users, in order to ensure that everyone has an interest in efficiency and the mitigation of adverse environmental impacts. To some extent, this has happened in recent decades in Spain, where taxpayers have in fact been asked to foot the bill for a significant part of water costs.

With these questions in mind, we examine the impact of spreading the high costs required to modernize and improve the efficiency of Spanish irrigation more widely. This approach is in line with recent research into shared environmental responsibility (see Munksgaard and Pedersen, 2001 [133]; Peters and Hertwich, 2006 [141]; Cadarso *et al*., 2009 [38]; and Lenzen *et al*., 2007 [107]). To this end, we apply a computable general equilibrium model (see Ballard *et al*., 1985 [17]; and Shoven and Whalley, 1992 [171])[30], which includes physical inputs (water), Government, and Trade sectors. The model works in an open economy, allowing joint analysis of the impacts of changes in water costs and agricultural productivity on consumption, exports and imports, and on the associated water savings.

The structure of the paper is as follows. After this introduction, the second section explains the current situation of the Upper Aragon Irrigation Scheme, a major irrigation scheme in the province of Huesca in north-eastern Spain, on which this study will focus. Section three explains the methodology applied and defines the different payment scenarios for modernization. The fourth, fifth and sixth sections analyse the results obtained from each of the scenarios simulated, and the paper ends with our conclusions and final reflections.

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[30] Lofting and McGauhey (1968 [113]) were the first to include water as an input in an Input-Output model. Meanwhile, input-output tables, or Social Accounting Matrices (SAM), and Computable General Equilibrium Models (CGEM) based on them, have become a common instrument in the analysis of water use and demand over the last decade (see, for example, Lenzen, 2009 [108]; and Lenzen and Peters, 2010 [109] for Australia; and Duarte *et al.*, 2002 [68]; Velázquez *et al.*, 2006 [183]; and Cazcarro *et al.*, 2010 [43] for Spain).

3.2.2. The Upper Aragon Irrigation Scheme

Huesca had 183,142 hectares of irrigated farmland in 2002, of which 122,248 hectares belonged to the *Comunidad General de Riegos del Alto Aragón* (CGRAA). The scheme also supplies water to several towns and cities, as well as ten industrial estates, and it is highly representative of irrigation in the Ebro valley. Moreover, the ready availability of data on water use and efficiency, costs and crop yields, mean that the CGRAA is ideally suited for the purposes of this study.

In recent years the CGRAA has come close to the physical limits of use, suffering serious water shortages in drought years and intense social pressure. As farmers and other users demand ever more new reservoirs, scientists and green groups have lobbied all the harder for cuts in the area under irrigation to contain and reduce environmental impacts. The current solution, which hinges on modernization by switching from blanket to aspersion or drip irrigation systems, has resulted in efficiency gains of between 10 and 15%.

Modernization has mainly been financed by farmers, who have improved the efficiency of irrigation and economic productivity to cover the additional costs.[31] However, they have also generated even greater pressure on water resources by intensifying output and switching to thirstier crops. Indeed, modernization costs threaten farming itself and could create serious problems for the rural community. In Table 3.1, the *cost of water* reflects payments to Government (taxes, investments and maintenance) and the irrigation communities, and the *cost of irrigation* represents other associated costs. The cost of water is 13.24% of the total cost, while modernization costs account for 66.65%, amounting to €552.77 per hectare. The problem for farmers, then, is to pay their modernization and irrigation costs.

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[31] To date, over 56,630 hectares have been modernized or are in the process of modernization. In recent years, the profitability of irrigated crops like alfalfa and maize has been above average for Spain. Meanwhile, the transformation process has generated improvements in water productivity of around 150% and similar land productivity gains. Current irrigation water use efficiency is over 60%, approximately 5% of which is attributable to the partial modernization already completed. Hence, the expected improvement will be between 10% and 15% at the end of the process. See DGA (2011b [58]).

Table 3.1. **Annual cost of modernised irrigation in the CGRAA, 2006**

	Average modernisation cost	
(A) Cost of water to farmers	(€/ha)	(%)
Payments to government	45.29	5.46
Payments to the Irrigation Community and the CGRAA	64.47	7.77
Total cost of water to farmers	*109.76*	*13.24*
(B) Cost of irrigation	(€/ha)	(%)
Labour	79.51	9.59
Modernisation of general networks	136.65	16.48
Apparatus	230.33	27.77
Power (pumping on plots)	169.96	20.49
Adaptation of plots	15.83	1.91
Sundry expenses	87.26	10.52
Total cost of irrigation	*719.54*	*86.76*
Total cost associated with water use (A+B)	829.3	100

Source: Own work based on Groot (2006 [89]).

Can CGRAA farmers afford modernization in this scenario? While the average net margins in the area are around €641 per harvest and hectare, their response has been to intensify production, increasing water demand across the board, despite adverse environmental outcomes. A possible solution would be to shift a part of the burden of modernization costs off the backs of direct users, which would reduce the pressure on the environment. The viability of this solution is supported by other cases like the Northern Victoria Irrigation Renewal Project in Australia, where the modernization of irrigation paid for both by government and by farmers has increased the efficiency of irrigation water use and made room for significant water savings, (see NVIRP, 2011 [134]).

Meanwhile, there is a clear consensus (see Lenzen and Peters, 2010 [109]; and Dey *et al*., 2007 [55]) that direct and indirect water uses are an important factor in any environmental analysis. The water embodied in products, dubbed *virtual water* by Allan (1993 [6]), is relevant both from a theoretical standpoint and for practitioners and politicians. In this regard, Hoekstra and Hung (2002 [94]) quantify the volume of virtual water in trade flows and identify the countries responsible for net imports and exports of virtual water.

Table 3.2 shows *per-capita* direct and virtual water use[32] in the Spanish province of Huesca. Households consume 161 litres/day/person, but total water use per capita is 26,432 litres/day, more than 160 times direct household consumption. Moreover, 6,645 litres of total per-capita use are imported from other regions of Spain or from abroad, while 18,134 litres, more than 2/3 of total domestic and imported uses, are exported. This means that the economy of Huesca is a net exporter of water.

Table 3.2. **Per capita virtual water use (litres/day) in Huesca (Spain)**

Sector	Use	Household virtual water consumption	Virtual water exports
Agriculture	17,571	1,178	6,384
Livestock	440	15	1,117
Energy Products and Water	429	124	92
Food, Beverages & Tobacco	19	2,077	5,208
Chemicals	858	62	281
Other industry	151	111	455
Construction & Engineering	6	13	0
Retailing	10	78	37
Hotels & Restaurants	31	1,537	25
Transport & Communications	3	18	7
Other Services	107	127	16
Soc., Gov., S/I	0	581	82
Households	161	161	0
Domestic total	19,786	6,082	13,704
Rest of Spain	4,729	1,631	3,099
European Union	1,774	532	1,242
Rest of the World	142	54	89
Total Foreign Sector	6,645	2,216	4,429
TOTAL (Sum)	26,432	8,298	18,134

Source: Cazcarro *et al.* (2010 [43]).

According to Table 3.2, Agriculture uses 17,571 litres of which only 1,178 end up as virtual water in the products sold to households. Indeed, the embodied water in products sold to households by the Agri-Food industry and Hotels and restaurants is greater than direct use by these sectors. The Agri-Food industry in fact uses only 19 litres per capita/day, but its products contain over 2,000 litres.

In light of the above, it would seem reasonable to apply different distribution criteria that would combine both payments for direct water use and payments for virtual water which is to say payments by direct users, indirect users and end-users. If direct (mainly agricultural) users paid a part of the significant costs involved, they would have an incentive to save and modernize, which would ease the financial burden on farmers and relieve pressure on the environment. In arid countries like Spain and Australia,

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[32] We account only for blue water use, and we identify "water use" with "physical consumption plus returns". Thus, "virtual water" means the embodied water use, not the embodied physical consumption. More details will be found in Cazcarro *et al.* (2010 [43]).

meanwhile, payments for the virtual water embodied in exports would undoubtedly encourage more rational water use and would probably produce savings. Finally, if end consumers had to pay for the water embodied in their consumption, they would be more likely to support saving and sustainability.

The use of these payment criteria requires reflection and more research, however. In this study, exporters' and consumers' contributions are paid by way of green export or consumption taxes levied in proportion to the amount of virtual water embodied in products. The model can also incorporate temporary and/or permanent changes in levels of water use, efficiency and technology through changes in the coefficients, production functions, consumption patterns, and tax rates, although these possibilities are limited by the scope of the study.

To sum up, mixed payment criteria are more complex but they have the potential to enhance environmental co-responsibility. This is the starting point for this paper, although the principle may also be applicable to other environmental problems, such as water pollution and atmospheric emissions.

3.2.3. Methodology

General Equilibrium Models (GEM) are widely applied as a tool for economic policy analysis, because they capture the general features and functioning of an economy and the interrelationships between producers, consumers, trade, government and other institutions. Models of this kind have been applied to environmental and water management in recent years. For example, Berck *et al*. (1991 [22]) used a CGEM to examine the utility of reducing water consumption to solve drainage problems in the San Joaquin Valley in California, and Dixon (1990 [67]) applied a model of this kind to analyse the impact and efficiency of water pricing in Melbourne, Sydney and Perth. Various studies employing CGEMs have been performed in Spain, including Velázquez *et al.* (2006 [183]), who examine the effects of raising the rates charged for water consumption in agriculture, and Gómez *et al.* (2004 [85]), who simulate possible water savings in the Balearic Islands.

A base scenario is a prerequisite for the application of any CGE model. This is usually a Social Accounting Matrix or SAM (see Kehoe, 1996 [102]). We use the 2002 SAM for the province of Huesca obtained from Cazcarro *et al*. (2010 [43]) as our base scenario (see point a) in the Annex.). The information for this SAM was obtained mainly from the 2002 MAPA (Spanish Ministry of Agriculture, Fisheries and Food) Agrarian Accounting Network, the National Statistics Institute of Spain and the regional Statistics Institute of Aragon.[33] As 2002 saw average rainfall in Huesca, the conclusions reached with regard to water use and savings will be correct on average. Finally, we built the CGEM taking the International Food Policy Research Institute (IFPRI) model as a guide (Löfgren *et al.*, 2002 [111]). This IFPRI model was defined and adapted to suit the objectives of the study, and it was solved using GAMS and calibrated to the 2002 SAM for Huesca. Hence, it describes the exact values of parameters and variables obtained in the base scenario.[34]

3.2.3.1. The model

The model used comprises 29 productive sectors, including irrigated and non-irrigated farming. Livestock is represented by a separate sector. The model also includes three production factors (labour, capital and water), accounts representing households and firms, a saving/investment account, a Government account, six tax accounts, and three trade sectors (Rest of Spain, European Union and Rest of the world). The water consumption data utilised were taken from Cazcarro *et al.* (2010 [43]).

Leontief production functions are used except for Irrigated Farming, because the use of a CES function for this sector provides an easy approximation to the efficiency gains obtained from the modernization of irrigation. Water is a physical input and the third factor of production. All prices are equal to 1 in the base scenario, except in the case of water. The water prices in the industrial accounts are obtained from AEAS (2002 [1]) and the price in the Irrigated Farming account is taken from Groot (2006 [89]). Hydroelectric plants also use water, of course, but they do not consume it physically, so these generating activities pay for water in the form of a tax. The model uses the demand elasticity coefficients obtained from the relevant literature for the Spanish economy, as shown in Table C.1 of the Appendix C. It is assumed that Government savings are flexible while tax rates are fixed. The exchange rate is also fixed, as the province of Huesca trades mainly in euros with the rest of Spain and the

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[33] As explained in Cazcarro *et al*. (2010 [43]), the 2002 SAM for Huesca was built in two steps. The first was the 1999 SAM for Aragon, and then the 2002 SAM for Huesca was obtained using the GRAS method described by Junius and Oosterhaven (2003 [101]) to update and regionalize data.

[34] Key modifications of the IFPRI model are shown in the Annex.

European Union. Finally, the total value of private saving is equal to investment in the model.

3.2.3.2. Virtual water

As explained above, the virtual or embodied water in a product is the water directly and indirectly required to produce it. In order to calculate the virtual water necessary to meet household and export demand, we will use the Leontief open linear model. If **A** is the Huesca matrix of total technical coefficients and **c** is its vector of unit water uses or water coefficients, the following equations

$$\boldsymbol{\lambda}' = \mathbf{c}'(\mathbf{I}\text{-}\mathbf{A})^{-1} = \mathbf{c}'\mathbf{M} \; ;$$

$$\Lambda(\mathbf{z}) = \boldsymbol{\lambda}'\mathbf{z}$$

can be used to obtain the vector of water values, $\boldsymbol{\lambda}$, which represents the water embodied in each unit of domestically produced goods, while $\Lambda(\mathbf{z})$ is the valuation of water for a given output **z**. Both **A** and **c** can be changed in the simulations, the components a_{ij} of **A** being the ratio between input i utilised in activity j and total output j (i.e. domestic output plus imports), while the components, c_j, of **c** are the ratio between water used directly in j and total output j.

We also assume that the water value of imports by Huesca province can be calculated with the above equations, using the Spanish unit coefficients as vector **c**, and the total technical coefficients for the Spanish economy as matrix **A**, since 60% of Huesca's imports are sourced from other regions of Spain.

3.2.3.3. Description of scenarios

The five scenarios described below simulate modernization for the total irrigated farmland in Huesca. We assume that farmers themselves always pay the annual modernization costs associated with equipment, the adaptation of fields, and 50% of the energy costs, included in the model as input costs (see Table 3.1), and they also make an additional annual payment of €40 million to Government for domestically used water[35]

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[35] The figure of €40 million includes modernization of general networks, 50% of energy costs and one and one half times the payment made to Government (see Table 3). The latter payment is due to the

to cover the remaining modernization costs. These contributions to Government are paid by way of taxes on users based on the criteria employed in each scenario (i.e. payments for activity, exports or consumption). According to the available data, these annual farmers' payments approximately cover the total modernization cost of the province's irrigated farmland.

Scenario 1: The distribution of additional payments is similar to that currently existing: direct users pay according to the quantity of water used, weighted on the basis of their returns, so that these payments are shared among irrigated farming, industry and services, and hydroelectric power plants at the percentages obtained in Table 3.3.

Scenario 2: In this scenario, direct users pay in proportion to their water use without corrective weightings. Equivalent consumption equal to 12.52% of irrigation uses is assumed to estimate payments by hydroelectric plants[36], which account for 84% of total payments in the Energy products sector.

Scenario 3: Only exporters pay in relation to the virtual water embodied in their exports. The real virtual water payment of the Energy products sector is increased by 543%, the better to capture payments by hydroelectric power plants.

Scenario 4: Only end consumers pay in proportion to the virtual water embodied in the product. Again the real virtual water payment of the Energy products sector is increased by 543% for payments by hydroelectric power plants.

Scenario 5: Mixed payment. One third is paid by direct users based on water use, and 2/3 by exporters and consumers in proportion to the virtual water in products.

Table 3.3. **Payments to Government in 2002 in the CGRAA**

Direct users	CGRAA	%	Weightings on returns
Irrigation	4,236,133	70.03	2
Industry and services	752,898	12.45	10
Hydroelectric plants	1,060,355	17.53	4
Total	6,049,386	100.00	

Source: Own estimations based on Groot (2006 [89]).

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current low level of payments, which has been sharply criticized by the green lobby because the amounts collected do not cover real costs or the cost of additional flow regulation requirements. According to these criteria, the exact payment based on Table 3 and the 183,142 hectares of Irrigated farming in Huesca in 2002 would be: (183,142/122,248)*4,236,133*(16.48/5.46+20.49/(2*5.46))+1.5) = 40,582,162.

[36] According to Table 3.3, equivalent consumption associated with hydroelectric plants will be a percentage of irrigation uses obtained as: (17.53/4)/(70.03/2)*100 = 12.52. Irrigation uses in Huesca's economy are around 1,355,069.33 Dm³, so equivalent consumption will be: 0.1252*1,355,069.33 = 169,654.68 Dm³. Energy products uses (not hydroelectric plants) are 31,223 Dm³ according to the available data, so equivalent consumption by hydroelectric plants is 543% of real Energy products uses (not hydroelectric plants). Consequently, we multiply the virtual water payments in scenarios 3 and 4 by 6.43, (i.e. 1+5.43), to approximate the payments made by hydroelectric power plants.

3.2.4. Effects of modernization without productivity gains

For ease of understanding, we separate the direct effects of modernization from indirect effects, which consist of agents' reactions to changes in prices, production and foreign trade. Direct effects always occur, but indirect effects depend on farmers' responses to higher costs, which is to say on final productivity. In this and the following section we therefore assume that farmers achieve 10% efficiency gains in their use of water for irrigation and the use coefficient for Irrigated farming is reduced accordingly, but farmers do not increase their productivity. In section 6, we also assume that farmers react to the increase in their costs by raising productivity, to obtain a general overview of the effects. In both cases, we shall focus especially on water savings.

Let us begin with the effects in scenario 1, which is the most similar to the current situation and is therefore the most likely under current political conditions. The increased payments arising from modernization are presented in Table 3.4, while changes in prices, exports and imports are shown in Tables 3.5 and 3.6.

Table 3.4. **Accounts with the top six tax payments (thousands of €) and no irrigation productivity gains**

Account	Scenario 1	%	Scenario 2	%	Scenario 3	%	Scenario 4	%	Scenario 5	%
Irrigated farming	28,010	70.03	31,967	79.92	16,932	42.33	6,107	15.27	19,846	49.61
Non-irrigated farming	0	0.00	0	0.00	368	0.92	185	0.46	210	0.52
Livestock	988	2.47	800	2.00	3,110	7.77	96	0.24	1,756	4.39
Energy products	7,921	19.80	4,739	11.85	1,487	3.72	4,829	12.07	3,219	8.05
Chemicals	1,928	4.82	1,561	3.90	786	1.96	482	1.21	985	2.46
Agri-food industry	43	0.11	35	0.09	16,047	40.12	15,734	39.33	10,649	26.62
Rubber, plastics and other manufactures	271	0.68	220	0.55	266	0.67	230	0.57	243	0.61
Retailing	22	0.05	18	0.04	53	0.13	342	0.86	97	0.24
Hotels and restaurants	70	0.18	57	0.14	77	0.19	10,742	26.85	2,137	5.34
Households	363	0.91	294	0.73	0	0.00	0	0.00	98	0.24
Total	40,000	100	40,000	100.00	40,000	100.00	40,000	100.00	40,004	100.00

Source: Own work.

Tax payments in scenario 1 are made basically by four sectors, namely Irrigated farming, Energy products, Chemicals and Livestock, which account for over 97% of the total. Payments from other accounts are negligible. As shown in Table 3.5, meanwhile, the accounts with the highest percentage price increases are Irrigated farming (13.91%), Energy products (1.84%) and Agri-Food industry (3.06%). In the latter case, the price increment is a consequence of dependence on Irrigated farming. In contrast, prices fall in relative terms in other sectors such as Livestock[37], Water, Chemicals, Transport material and Rubber, plastics and other manufactures, because they are accounts with low payments. Table 3.6 also reveals that the biggest falls in exports in scenario 1 are in Irrigated farming, Non-irrigated farming and the Agri-food industry. Imports also shrink, but the percentage decline is less than in the case of exports, because some imported goods become relatively cheaper than domestic goods. An exception is Energy products, where imports increase due to rising demand after modernization because of dependence on external markets.

Table 3.5. **Accounts with the six biggest percentage change in prices (absolute value) and no irrigation productivity gains**

Account	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Irrigated farming	13.91	15.37	7.39	6.48	10.46
Livestock	-2.87	-3.24	-2.36	-1.78	-1.70
Energy products	1.84	-0.82	-3.18	0.36	-2.12
Water	-6.91	-7.86	-9.09	-3.12	-6.67
Chemicals	-2.29	-2.62	-2.91	-1.18	-2.14
Transport material	-2.88	-3.01	-2.30	-4.29	-3.27
Agri-food industry	3.06	3.36	3.50	3.40	3.84
Rubber, plastics and other manufactures	-2.54	-2.84	-2.89	-1.66	-2.39
Hotels and restaurants	-0.02	0.06	0.15	1.38	0.40
Average change	*-0.07*	*-0.15*	*-0.39*	*-0.56*	*-0.37*
Standard deviation of price increase	*3.20*	*3.59*	*2.67*	*1.96*	*2.73*

Source: Own work.

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[37] One would expect Livestock sector prices to raise as a consequence of dependence on Irrigated farming. However, we have to take into account that Livestock sector also depends on Non-irrigated farming (a similar volume to the Irrigated farming demand), Chemicals, Metal products and machinery, Construction and engineering and Transport and communications, whose prices fall. Moreover, Huesca's Livestock sector demands a relevant part of the livestock feed from the rest of Spain, the EU and the rest of the world, whose prices in the model are constant.

Table 3.6. **Sectors with the six biggest percentage changes (absolute value) in exports and imports and no irrigation productivity gains**

Account	Exports					Imports				
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Irrigated farming	-40.92	-43.74	-47.52	-16.30	-33.24	-3.94	-4.12	-11.55	-6.51	-6.33
Non-irrigated farming	-9.34	-10.23	-16.76	-5.98	-12.23	-11.06	-11.91	-14.22	-8.28	-11.36
Livestock	-0.76	-0.18	-9.27	-3.83	-9.10	-16.17	-17.51	-19.27	-11.25	-15.13
Energy products	2.75	13.41	16.50	15.70	15.04	10.84	9.61	8.29	7.27	7.75
Chemicals	20.54	24.23	25.57	7.26	12.29	1.95	2.49	1.91	0.30	-0.05
Transport material	35.03	36.88	28.49	36.40	28.68	4.84	5.07	5.23	2.05	3.61
Agri-food industry	-18.67	-20.16	-24.20	-11.55	-17.76	-5.07	-5.42	-5.60	-6.67	-5.10
Rubber, plastics and other manufactures	15.23	17.01	16.80	7.65	10.43	1.94	1.97	2.01	0.74	1.27
Recoveries and repairs	18.59	19.71	15.52	23.44	16.98	8.32	8.84	6.81	10.60	7.47

Source: Own work.

Total tax payments are the same in all scenarios, but their distribution and tax nature differ, as in scenario 2, where direct users pay in proportion to domestic water use, but without the profitability weightings established in scenario 1. The distribution of payments is very similar to scenario 1, which indicates that the weightings have little effect. This is relevant because changing these weightings has been widely mooted in political debate. In Table 3.4, the four highest paying accounts are the same as in scenario 1, and in the same order, accounting for 97.67% of payments in scenario 2 and 97.12% in scenario 1. However, the payments made by Energy products fall from 19.80% of the total in scenario 1 to 11.85% in scenario 2.

In scenario 3, where exporters pay taxes in proportion to the virtual water embodied in their exports, the highest-paying accounts are Irrigated farming and Agri-Food industry, which respectively account for 42.33% and 40.12% of the total, due to their share in exports. Agri-Food industry is particularly significant, representing more than 40% of payments, compared to less than 0.2% in scenarios 1 and 2.

In scenario 4, tax charges are paid only by the end consumer. The top positions in Table 3.4 are occupied by Agri-Food industry and Hotels and restaurants, which respectively account for 39.33% and 26.85% of payments. This is due both to the significant share of their products in Household spending and to virtual water values. In contrast, the share of the Hotels and restaurants account was minimal in scenario 3 because the sector does not export.

Scenario 5 is based on a mixed payment criterion, as explained above, so its rankings are a combination of the preceding scenarios. The highest paying accounts in descending order are Irrigated farming, Agri-food industry, Hotels and restaurants, Energy products, and Livestock.

Table 3.5 presents changes in prices in each of the scenarios. Scenarios with tax charges for virtual use are less inflationary in Irrigated farming, while their standard deviations are smaller. The steepest falls in prices are found in the same accounts in all scenarios, namely Water utilities, Livestock, Chemicals, Transport material, and Rubber, plastics and other manufactures. Meanwhile, Irrigated farming and Agri-food industry are the two sectors with the highest increments, as was to be expected. Changes in scenario 2 are again similar to those in scenario 1, confirming the weakness of the policies to change the profitability weightings when the payments are shared out.

In terms of trade (see Table 3.6), farm exports fall in all scenarios because of rising costs, and Agri-Food industry exports also shrink. In scenario 3, the effects on exports are stronger than in any of the other scenarios because modernization is paid for by exporters alone through tax charges.

To sum up, the *payment criterion* is a relevant economic and environmental policy issue, given the differing impacts on the distribution of payments, prices, exports and imports.

3.2.5. Water savings in domestic and trade markets

As in the preceding section, we shall assume that farmers do not obtain any productivity gains. Within this framework, let us estimate water savings as the difference between initial virtual water and final virtual water in products.[38] The results for household consumption and exports are presented in Table 3.7, which refers only to domestic water uses.[39]

The key result from Table 3.7 is that significant water savings are obtained through a decline in farm exports in all of the scenarios, driven mainly by falling demand in the Irrigated farming and Agri-Food industry accounts, while increased water use is found mainly in industrial and service sectors. Export savings are, then, clearly

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[38] Water savings are defined in the Annex b).

[39] We also estimated water savings taking all uses (domestic and imported water) into account. Both the total figures and percentages found are slightly higher than in the case of domestic water uses alone, but the qualitative conclusions are the same. (See Table 3.10).

related with price increases in the different accounts, although water values and demand elasticities also play a role.

Table 3.7 also shows that export savings are above 7.55% in all of the scenarios, rising to 14.23% in scenario 3. The meaning of these figures can best be understood in light of the efficiency gains in water use by Irrigated farming (10% of use in this sector), which drives a reduction of approximately 8.88% in total domestic uses.[40]

Table 3.7 also shows that domestic use tends to rise with modernization except in scenario 4, especially in the Agri-Food industry, Hotels and restaurants and Irrigated farming accounts, because domestic consumption by households substitutes exports.

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[40] Total water use in Huesca's economy is around 1,525,910 Dm^3, and efficiency gains from Irrigated farming produce a saving of 135,506.93 Dm^3.

Table 3.7. **Changes in domestic water use (Dm^3) and no irrigation productivity gains**

Sector	Households					Exports				
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Irrigated farming	2,582	3,083	9,177	-4,352	2,267	-157,585	-167,890	-177,624	-72,805	-126,302
Non-irrigated farming	157	178	225	-70	88	-237	-232	-924	-528	-836
Livestock	184	208	245	-4	126	12,145	14,379	6,307	-433	440
Energy products	1,549	2,001	2,488	445	1,557	1,638	2,920	3,465	1,724	2,490
Water utilities	88	97	117	17	75	8	10	10	1	4
Minerals and metals	0	0	0	0	0	32	36	39	18	28
Minerals and non-metal products	6	7	8	2	5	254	292	315	142	228
Chemicals	1,685	1,893	2,251	364	1,355	11,872	13,850	14,925	4,083	8,106
Metal products and machinery	88	98	121	17	76	2,424	2,676	2,604	1,715	2,105
Transport material	62	68	76	24	52	814	892	785	610	650
Agri-food industry	6,689	7,937	15,782	-11,418	3,258	-60,595	-64,118	-75,305	-53,380	-63,333
Textiles, leather and footwear	282	317	468	-90	227	232	257	325	6	186
Paper, stationery and printing	216	243	323	14	182	2,136	2,401	2,296	1,526	1,680
Wood, cork and wooden furniture	14	17	24	-1	12	359	415	382	553	399
Rubber, plastics and other manufactures	816	907	1,092	143	667	3,522	3,970	4,134	1,412	2,595
Construction and engineering	0	0	0	0	0	5	5	6	2	4
Recoveries and repairs	0	0	0	0	0	7	8	7	5	6
Retailing	746	859	1,082	95	639	415	473	539	144	343
Hotels and restaurants	7,144	8,097	16,975	-11,996	5,081	123	137	234	-163	77
Transport and communications	176	208	271	17	159	73	86	97	29	63
Banking and insurance	42	53	82	-32	32	2	3	4	-1	2
Real estate	366	418	529	45	303	34	38	45	9	27
Private education	49	56	75	-4	39	3	3	4	0	2
Private healthcare	323	365	451	37	258	9	11	12	2	7
Retailing	244	277	358	12	205	123	139	153	47	100
Domestic service	0	0	0	0	0	0	0	0	0	0
Public education	4	5	6	0	3	0	0	0	0	0
Public healthcare	64	72	88	9	51	2	3	3	1	2
Public services	29	32	44	-3	24	1	1	1	0	1
Total variation in water use (Dm^3)	*23,605*	*27,496*	*52,359*	*-26,731*	*16,741*	*-182,182*	*-189,237*	*-217,161*	*-115,281*	*-170,925*
% Total variation in water use	*1.55*	*1.80*	*3.43*	*-1.75*	*1.10*	*-11.94*	*-12.40*	*-14.23*	*-7.55*	*-11.20*

Source: Own work.

3.2.6. Modernization with agricultural productivity gains.

Let us now incorporate the agricultural productivity gains to capture all of the general effects. These productivity gains are the result of farmers' reactions to increasing modernization costs. Therefore, we shall now change the efficiency parameter of the CES functions for Irrigated farming. The remaining accounts continue to be based on a Leontief technology.[41] As productivity gains depend on multiple factors (e.g. irrigation know-how, agricultural research and product marketing), we shall examine the problem at three levels of gains (5%, 10% and 15%), seeking qualitative data. Tables 3.8 and 3.9 show the main effects on prices and exports in each of the five scenarios.

As shown in Table 3.8, prices in Irrigated farming are lower in all scenarios as productivity increases, and in some cases they even fall. The same effect occurs in the Agri-Food industry, indicating that agricultural productivity gains are the correct response to increasing modernization costs.

Table 3.9 shows the effects of productivity gains on exports. In all of the scenarios, rising productivity mitigates the fall in Irrigated and Non-irrigated farming exports, and the contraction observed in Livestock and Agri-food industry exports in Table 3.6. In some cases, in fact, exports actually grow. In other words, these productivity gains neutralise or reduce the effects of modernization costs (see Tables 3.5 and 3.6).

Let us now turn to water saving and use. Table 3.10 compares the use of domestic water in percentage terms and reveals some of the trends caused by productivity gains. On the one hand, savings via exports fall with higher productivity in all scenarios, because productivity gains boost output and exports. However, productivity gains also cause a reduction in the virtual water consumed by households, with the result that savings are achieved in all sectors in the case of a 15% gain. Nevertheless, the levels of saving achieved via household consumption vary widely, between 0.49% in scenario 3 and 5.89% in scenario 4. This variability once again demonstrates the importance of payment criteria for environmental policy design.

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[41] CES technology is used for the Irrigated farming account because it facilitates the estimation of changes in productivity. However, we also estimated changes in Irrigated farming on the basis of Leontief technology, obtaining qualitatively similar results.

Table 3.8. **% Effects on prices with agricultural productivity gains**

Productivity	5%					10%					15%				
Account*	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Irrigated farming	9.12	10.56	3.04	1.41	5.58	4.59	6.02	-1.07	-3.40	0.98	0.27	1.69	-4.97	-7.98	-3.37
Livestock	-2.55	-2.96	-2.20	-1.50	-1.68	-2.13	-2.57	-1.95	-1.12	-1.58	-1.59	-2.08	-1.61	-0.64	-1.40
Energy products	2.77	0.09	-2.45	1.39	-1.38	3.76	1.04	-1.68	2.47	-0.61	4.81	2.06	-0.86	3.61	0.19
Water	-5.50	-6.53	-8.03	-1.51	-5.60	-3.92	-5.04	-6.86	0.27	-4.44	-2.13	-3.36	-5.53	2.26	-3.16
Chemicals	-1.79	-2.14	-2.52	-0.66	-1.77	-1.25	-1.62	-2.09	-0.10	-1.37	-0.67	-1.06	-1.63	0.51	-0.95
Transport material	-1.81	-1.94	-1.38	-2.91	-2.07	-0.84	-0.97	-0.55	-1.67	-0.98	0.04	-0.08	0.20	-0.54	0.01
Agri-food industry	1.89	2.19	2.46	2.04	2.58	0.77	1.06	1.46	0.73	1.37	-0.31	-0.01	0.51	-0.52	0.21
Rubber, plastics and other manufactures	-1.93	-2.25	-2.39	-0.99	-1.87	-1.28	-1.62	-1.87	-0.29	-1.33	-0.59	-0.95	-1.31	0.44	-0.77
Hotels and restaurants	-0.07	0.01	0.11	1.31	0.35	-0.12	-0.04	0.07	1.24	0.29	-0.18	-0.10	0.02	1.16	0.22
Average change	*-0.03*	*-0.12*	*-0.37*	*-0.48*	*-0.32*	*0.03*	*-0.06*	*-0.33*	*-0.38*	*-0.26*	*0.11*	*0.01*	*-0.28*	*-0.26*	*-0.19*
Standard deviation of price increase	*2.27*	*2.61*	*1.99*	*1.08*	*1.79*	*1.50*	*1.70*	*1.57*	*0.99*	*1.07*	*1.08*	*0.99*	*1.54*	*1.76*	*0.97*

Source: Own work.

** The accounts in this table are the same as in Table 3.5.*

Table 3.9. **% Effects on exports with agricultural productivity gains**

Productivity	5%					10%					15%				
Account*	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Irrigated farming	-29.86	-33.30	-38.30	-3.51	-24.04	-16.92	-21.13	-27.67	11.08	-13.76	-1.74	-6.89	-15.38	27.80	-2.24
Non-irrigated farming	-5.40	-6.32	-13.57	-1.93	-8.77	-1.48	-2.42	-10.43	2.09	-5.32	2.41	1.46	-7.34	6.07	-1.90
Livestock	2.74	3.52	-5.94	-0.15	-5.27	5.60	6.61	-3.09	3.11	-1.70	7.75	9.01	-0.77	5.90	1.58
Energy products	-0.62	9.66	13.30	12.74	12.89	-4.07	5.83	10.01	9.71	10.69	-7.62	1.91	6.60	6.59	8.42
Chemicals	15.53	19.16	21.34	4.09	9.87	10.43	14.01	16.98	0.87	7.39	5.23	8.78	12.47	-2.43	4.83
Transport material	20.19	21.77	16.63	21.70	16.94	8.47	9.86	7.02	10.13	7.48	-1.07	0.18	-0.97	0.75	-0.34
Agri-food industry	-12.63	-14.23	-19.26	-5.85	-12.97	-6.45	-8.14	-14.24	-0.07	-8.14	-0.12	-1.91	-9.16	5.80	-3.26
Rubber, plastics and other manufactures	10.95	12.74	13.27	4.28	7.72	6.79	8.59	9.80	1.04	5.10	2.68	4.51	6.36	-2.12	2.54
Recoveries and repairs	11.68	12.77	9.63	16.45	11.09	5.42	6.49	4.29	10.16	5.79	-0.26	0.78	-0.57	4.50	1.01

Source: Own work.

** The accounts in this table are the same as in Table 3.6.*

Table 3.10. **Total water changes (%) in the different scenarios**

		Via households					**Via exports**					**Via households + Via exports**				
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Domestic water	0% productivity gains	1.55	1.80	3.43	-1.75	1.10	-11.94	-12.40	-14.23	-7.55	-11.20	-10.39	-10.60	-10.80	-9.31	-10.10
	10% productivity gains	-1.28	-0.92	0.89	-4.46	-1.17	-7.96	-8.46	-10.56	-4.42	-8.06	-9.24	-9.38	-9.67	-8.88	-9.23
	15% productivity gains	-2.81	-2.39	-0.49	-5.89	-2.37	-6.09	-6.60	-8.81	-3.04	-6.62	-8.90	-8.99	-9.30	-8.93	-8.99
Total water (domestic and imported)	0% productivity gains	1.82	2.05	3.69	-1.26	1.49	-9.77	-10.17	-11.98	-5.82	-9.22	-7.95	-8.11	-8.29	-7.07	-7.73

Source: Own work.

Considering households and exports together, savings are achieved in all scenarios at the level of 15%, varying between 8.90% and 9.30%. These savings are slightly lower than those obtained without productivity gains. This is because output will tend to increase in step with productivity gains. Let us recall here that efficiency gains in water use (due to agricultural productivity gains) were approximately 8.88% in total domestic uses. Therefore, at the level of 15% productivity gains the water saving is reduced to that obtained via technology.

On a scenario-by-scenario basis, Table 3.10 reflects very similar results for scenarios 1 and 2 (direct user payments), although the saving is less in scenario 1 and is achieved mainly via exports. Scenario 3 produces the highest savings via exports for all three levels of productivity gains, as was to be expected. It is also the scenario that displays the biggest water demand via households in all three cases, resulting in savings of 0.49% for a 15% productivity gain. The highest savings via households are found in scenario 4, which was also the case without productivity gains. However, this scenario provides the smallest savings via exports, (3.04% at the 15% level). Finally, the mixed scenario again reflects the general trend: savings via exports decline with productivity gains while household savings increase.

3.2.7. Conclusions and final remarks

The study looks at water use in the province of Huesca in north-eastern Spain. Many scientists believe that economic uses of water are very close to the sustainable maximum in this region, as is indeed the case in the rest of Spain and in other arid countries like Australia.

In accordance with the Water Framework Directive and recent Spanish legislation, the costs of modernization must be paid largely by direct water users, which is to say by farmers. Table 3.1 shows annual modernization costs for the Upper Aragon Irrigation Scheme, a major scheme in the Ebro valley, which we have taken as our benchmark. These modernization costs are very high, placing a barely sustainable burden on farmers, and their response has either been to abandon farming or to intensify cropping, increasing the pressure on water resources.

However, this modernization benefits society as a whole and, though irrigation does generate income for farmers, it is also essential to produce many goods for export, which generate earnings for the region, and provide basic inputs for other sectors. In this light, it has been widely argued that all water users are to some degree responsible for modernization, and its costs should be shared more fairly among direct users (e.g. farmers and hydroelectric plants), indirect users (e.g. Agri-Food industry) and end users like households and exporters. This ties in with the debate about how the liability for atmospheric emissions should be shared among different users and countries. It is also an advance in the analysis of green tax policy for consumers, exporters and the Agri-food industry to favour more efficient water use.

The study assumes that the modernization cost is borne by farmers and Government, which recovers its investment through an annual tax charge of €40 million payable by users. Our analysis focuses on the outcomes produced by 5 different distribution criteria for tax payments. In two of these scenarios (1 and 2), payments are made only by direct users. In scenario 3 only exporters pay, and in scenario 4 only households. Scenario 5 combines the criteria employed in scenarios 2, 3 and 4. The five scenarios were examined in two situations, with and without agricultural productivity gains. The comparison of the two situations reveals initially that it is necessary to promote productivity gains to compensate for modernization costs, but also to neutralize the negative effects of these costs.

Another clear conclusion is that the distribution of payments is far from being a secondary matter but has important macroeconomic and social consequences that should be taken into account in environmental water policy. Farmers' payments in scenarios 3, 4 and 5 would be much smaller than in scenarios 1 and 2, which would certainly increase the viability of existing farms and would reduce the upward pressure on water demand caused by modernization. Payments have very significant effects on prices (see Table 3.5), but these price shifts also depend to a great extent on the type of payment made. Irrigated farming and Agri-Food industry display the largest price increases in all scenarios. However, scenarios 3 and 4 have much smaller inflationary effects and distort prices less. A policy of sharing water costs among direct users, indirect users and end-users is difficult to apply. In the case of exporters, the main problem would be to differentiate between products, because the policy could cause problems of competitiveness in an integrated trade block like the European Union (EU). In the case of payments for the virtual water embodied in consumption, it would be similar to a green tax that would mainly affect products from the Agri-food industry and Hotels and restaurants. Moreover, the hydrological, agronomic and geographical variables affecting the virtual water embodied in products need to be taken into account. Therefore, reforms of this kind require unanimity between the trade block's member nations, new tax criteria and detailed regional studies. Even so, now may be the moment to consider a green tax in proportion to the virtual water embodied in products, in light of the insights gleaned from current and future research.

Modernization also has significant effects on trade. Table 3.6 reveals export contraction under the assumption of no productivity gains. The four accounts showing the largest percentage falls in exports are Irrigated farming, Non-irrigated farming, Livestock and Agri-Food industry, although the decline in exports substantially depends on the nature of the payments. As was to be expected, the sharpest fall is found in scenario 3, where tax payments are assigned to exporters in their entirety. The smallest drop is in scenario 4, where the tax is paid by households. These results change, however, when productivity gains are included in the model. In general, these gains reduce or neutralize the effects presented in Table 3.5. In fact, prices may even fall when productivity gains are at the 15% level.

A similar result was found for exports: productivity gains make products associated with Irrigated farming cheaper (e.g. Agri-food industry products), thereby boosting demand. As a consequence, the falls in exports found when the scenarios were estimated without productivity gains either disappear or shrink.

Let now us consider how modernization affects the environment through water use. Table 3.7 reflects changes in water demand without productivity gains, and Table 3.10 presents the aggregate figures for all sectors. Let us remember here that the figures shown in these tables reflect virtual water values (i.e. the water directly and indirectly necessary to obtain a given product). As the Table 3.10 shows, there is a clear difference between the savings obtained in exports and households. If productivity gains are at the 0% level, all sectors save water via exports, but the water embodied in household consumption increases (except in scenario 4). This difference is to some extent valid for the other productivity levels, since savings in households and exports move in opposite directions when productivity increases.

The aggregate saving (see Table 3.10) varies surprisingly little in the different situations and scenarios proposed, fluctuating between 8.88% and 10.80% of total water uses. In fact, the saving is around 9% in all cases, which is the level of technological saving produced by modernization. In other words, water savings are mainly produced by improvements in technological use, and farmers are the main agents of these savings. Furthermore, the savings achieved by changes in consumption and export patterns are socially and culturally very important, but less so quantitatively. The 8.88% of savings produced by technological innovation hardly varies. This is a crucial result for environmental policy and water management.

3.2.8. Appendix C

3.2.8.1. About the SAM used in the model

The Social Accounting Matrix for Huesca province used in this study has the following basic structure:

	1	**2**	**3**	**4**	**5**	**6**	**7**	**TOTAL**
1. PRODUCTIVE ACTIVITIES	C_{11}	0	0	C_{14}	C_{15}	C_{16}	C_{17}	C_{1j}
2. PRODUCTIVE FACTORS	C_{21}	0	0	0	0	0	0	C_{2j}
3. FIRMS	0	C_{32}	C_{33}	C_{34}	0	C_{36}	C_{37}	C_{3j}
4. PUBLIC SECTOR	C_{41}	C_{42}	C_{43}	0	C_{45}	C_{46}	C_{47}	C_{4j}
5. SAVINGS-INVESTMENTS	0	0	C_{53}	C_{54}	0	0	C_{57}	C_{5j}
6. FOREIGN SECTOR	C_{61}	0	C_{63}	C_{64}	C_{65}	0	C_{67}	C_{6j}
7. HOUSEHOLDS	0	C_{72}	C_{73}	C_{74}	0	C_{76}	C_{77}	C_{7j}
TOTAL	C_{i1}	C_{i2}	C_{i3}	C_{i4}	C_{i5}	C_{6}	C_{7}	

Source: Own work.

The SAM for Huesca comprises 29 productive sectors, including irrigated and non-irrigated farming, three production factors (labour, capital and water), accounts representing households and firms, a saving/investment account, seven accounts for the Public Sector (a Government account and six tax accounts), and three trade sectors (Rest of Spain, European Union and Rest of the world). The water consumption data utilised were taken from Cazcarro *et al.* (2010 [43]).

3.2.8.2. About the CGEM used

Taxes are included in the model after calibration as follows:

$$TAXPAR('TX',AC) = TAXPAR('TX',AC) + Scenario('TX',AC);$$

using the tax rates defined by

$$t_{AC} = TAXPAR\ ('TX',AC)/(SAM(AC,'TOTAL'));$$

where *TAXPAR* is the set of tax accounts, *TX* comprises activity taxes, export taxes and consumption taxes, *AC* represents activities or commodities, and *Scenario* is the increment in payments in each scenario.

A CES production technology is used for irrigated farming, given by:

$$QA_a = \alpha_a^a \cdot (\delta_a^a \cdot QVA_a^{-\rho_a^a} + (1 - \delta_a^a) \cdot QINTA_a^{-\rho_a^a})^{\frac{-1}{-\rho_a^a}}$$

$$\frac{QVA_a}{QINTA_a} = \left(\frac{PINTA_a}{PVA_a} \cdot \frac{\delta_a^a}{1 - \delta_a^a}\right)^{\frac{1}{1+\rho_a^a}}$$

and α_a^a is used to change the level of agricultural productivity. The production technology for the rest of the activities is a Leontief technology, represented by:

$$QVA_a = iva_a \cdot QA_a$$

$$QINTA_a = inta_a \cdot QA_a$$

We estimate the water savings in the model as the following differences:

$$water\ saving\ via\ exports_c = \boldsymbol{\lambda}^{\mathbf{1}} \cdot QE.L_c - \boldsymbol{\lambda}^{\mathbf{0}} \cdot QEC_c$$

$$water\ saving\ via\ households_{c,h} = \boldsymbol{\lambda}^{\mathbf{1}} \cdot QH.L_{c,h} - \boldsymbol{\lambda}^{\mathbf{0}} \cdot QHC_{c,h}$$

where QEC_c are the exports in the calibration scenario; $QE.L_c$ are exports in the final scenario; $QHC_{c,h}$ is household consumption in the calibration scenario; $QH.L_{c,h}$, is household consumption in the final scenario; $\boldsymbol{\lambda}^{\mathbf{0}}$ is the vector of water values in the calibration scenario; and $\boldsymbol{\lambda}^{\mathbf{1}}$ is the vector of water values in the final scenario.

Finally, the consumer price index *(CPI)* is fixed and functions as the numéraire in the model.

$$\overline{CPI} = \sum_{c \epsilon C} PQ_c \cdot cws_c$$

where $cwts_c$ is the weight of commodity *c* in the consumer price index and PQ_c is the price of composite good *c*.

3.2.8.3. About the elasticity coefficients

Table C1. **The elasticity coefficients**

Armington elasticity			0.8
CET elasticity			1.6
Demand elasticity coefficients			
Irrigated land and non-irrigated farming[1]	0.83	Construction and engineering[1]	0.75
Livestock[2]	0.92	Recoveries and repairs[1]	1.31
Energy products[1]	0.56	Retailing[1]	0.96
Water[1]	0.71	Hotels and restaurants[1]	1.70
Minerals and metals[1]	1.45	Transport and communications [1]	1.14
Minerals and non-metal products[1]	0.51	Banking and insurance [1]	1.04
Chemicals[1]	1.00	Real estate[1]	0.46
Metal products and machinery[1]	1.45	Private education[1]	0.65
Transport material[1]	1.05	Private healthcare[1]	0.64
Food, beverages and tobacco[1]	0.83	Retailing[1]	1.16
Textiles, leather and footwear[1]	1.29	Domestic service[1]	1.16
Paper, stationery and printing[1]	1.35	Public education[1]	0.65
Wood, cork and wooden furniture[1]	0.44	Public healthcare[1]	0.64
Rubber, plastics and other manufactures [1]	1.31	Public services[1]	1.16

[1] Mainar, A. (2010 [115]).

[2] Radwan, *et al.* (2009 [149]).

Chapter 4

Strategies regarding future water availability

4.1. Presentation

In this fourth chapter we present an empirical application of the dynamic model developed in chapter 2 above. This application refers to the actual evolution of water supplies in the province of Huesca in recent years, which is used as a basis for a forecast with a 2028 time horizon. This evolution, which was presented in the chapter 1 (Figure 1.1), reveals a decreasing trend in water availability. In order to present a wider temporal and geographical overview, however, we analyse the water resources of the Ebro river basin from 1913 to 2013 in the next section, showing the relevance of the water forecast assumed in this chapter.

After analysing this evolution, we address the design of strategies to cope with restrictions and ensure the availability of water even in extreme events such as drought, one of the main objectives of the thesis. The core strategies focus on smoothing the impacts of water constraints through an improvement in resource management in irrigated agriculture. In addition to technological change, we consider the Water Framework Directive (EC 2000/60 [64]), which establishes water cost recovery as a key goal. In a context in which limits are placed on natural resources, finding new designs for water pricing policies could be a challenge. Therefore, we assess strategies that combine pricing water for irrigation and improved technology. The results show that future water availability can be assured even in the event of drought by reversing the negative long-term economic trend through policy strategies to foster technical progress. As outlined below, this chapter also confirms that lower price volatility achieved through a water pricing policy could improve the optimal use of water.

4.2. Water resources in the Ebro river basin. A century of evolution (1913–2013)

This section presents the evolution of the available water resources in the Ebro basin over the one hundred years from 1913 to 2013. It is an update of the data presented in Sánchez-Chóliz (2005 [160]), and it aims to confirm two essential issues which have motivated further development of prevention and compensation policies, namely the decline and the irregularity of water availability.

The annual series *Water flows in Tortosa* and *Water flows plus water consumption in Tortosa* are taken as the basis for this purpose, as well as the *Water flows in Zaragoza* annual series, which provides a guide for the period between 1935 and 1951, which is not available in the *Water flows in Tortosa* series. These allow us to solve the major problem of uncertainty and weaknesses in the water information available for the period of the Spanish Civil War and its aftermath. The series presented in Table 4.1 are based information provided by the Ebro Water Board (CHE [59]), specifically consisting of data collection at flow gauging stations number 11 (Zaragoza), 24 (Segre in Lleida) and 27 (Tortosa), which are found in the section on historical data.[42] In the case of the *Water flows in Tortosa* series, we apply the criteria described in MMA (2000 [132]) for some missing years (particularly from 1940 to 1951): "*Water flows in Tortosa* = 1.1 * *Water flows in Zaragoza* + 2.1 * *Water flows in Segre in Lleida*". Finally, to obtain the *Water flows in Tortosa* series for the period from 1935 to 1940, which covering the years of the Spanish Civil War, we consider only the information available in *Water flows in Zaragoza*, to which we apply the average increase between *Water flows in Zaragoza* and *Water flows in Tortosa* for the periods 1930-1935 and 1940-1945, for which complete information exists in both series. Data for the period 2008–10 were obtained from the Yearbook of Water flows [60] also provided by the CHE, and the latest data for the period 2010–2013 were obtained from the Automatic Ebro Basin Hydrological Information System (SAIH in its Spanish acronym [61]).

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[42] Some isolated cells have been completed with the average value for the month (previous and following year, and/or the previous and following month).

Table 4.1. **Water flows in Zaragoza and Tortosa (hm^3)**

	Zaragoza	Tortosa		Zaragoza	Tortosa		Zaragoza	Tortosa
1913-14	5,872	20,568	**1947-48**	5,255	10,521	**1981-82**	5,520	7,458
1914-15	9,601	30,821	**1948-49**	2,308	4,051	**1982-83**	9,297	13,931
1915-16	7,362	27,794	**1949-50**	5,930	9,791	**1983-84**	6,935	9,839
1916-17	6,696	24,739	**1950-51**	9,579	16,873	**1984-85**	7,886	9,171
1917-18	4,716	14,562	**1951-52**	7,510	17,946	**1985-86**	5,253	6,922
1918-19	8,925	22,565	**1952-53**	7,030	16,982	**1986-87**	4,874	6,995
1919-20	5,538	20,748	**1953-54**	9,986	16,018	**1987-88**	10,384	18,032
1920-21	4,178	15,618	**1954-55**	4,515	8,607	**1988-89**	2,852	10,442
1921-22	5,075	17,071	**1955-56**	7,818	15,816	**1989-90**	2,456	4,284
1922-23	4,438	14,858	**1956-57**	4,474	8,270	**1990-91**	5,904	9,448
1923-24	5,416	16,017	**1957-58**	5,701	9,056	**1991-92**	5,103	6,042
1924-25	3,907	12,398	**1958-59**	5,870	14,256	**1992-93**	6,949	10,433
1925-26	4,804	16,778	**1959-60**	13,670	28,745	**1993-94**	5,952	8,745
1926-27	5,525	19,491	**1960-61**	12,212	22,556	**1994-95**	4,741	7,900
1927-28	8,877	19,439	**1961-62**	13,562	21,994	**1995-96**	4,861	10,223
1928-29	5,608	10,792	**1962-63**	8,385	17,658	**1996-97**	7,373	13,122
1929-30	13,417	21,876	**1963-64**	6,315	15,194	**1997-98**	5,870	10,227
1930-31	13,441	19,177	**1964-65**	7,103	10,786	**1998-99**	5,325	6,340
1931-32	7,801	14,178	**1965-66**	10,186	18,817	**1999-00**	4,539	6,987
1932-33	8,370	14,383	**1966-67**	8,508	13,884	**2000-01**	7,445	12,661
1933-34	10,073	13,923	**1967-68**	9,966	15,552	**2001-02**	2,282	4,121
1934-35	9,006	15,034	**1968-69**	8,103	17,558	**2002-03**	8,706	12,161
1935-36	15,264	28,233	**1969-70**	9,718	14,438	**2003-04**	8,189	14,007
1936-37	7,513	13,895	**1970-71**	7,346	14,359	**2004 -05**	5,383	6,699
1937-38	9,665	17,876	**1971-72**	10,050	19,333	**2005-06**	4,908	6,011
1938-39	11,674	21,592	**1972-73**	7,326	12,781	**2006-07**	6,988	7,895
1939-40	8,183	15,135	**1973-74**	5,746	11,826	**2007-08**	5,625	7,048
1940-41	12,534	21,871	**1974-75**	8,803	13,709	**2008-09**	7,596	10,265
1941-42	5,958	12,527	**1975-76**	6,069	8,419	**2009-10**	6,601	9540
1942-43	4,901	11,653	**1976-77**	8,761	15,476	**2010-11**	4,360	6,574
1943-44	3,845	10,578	**1977-78**	12,016	17,761	**2011-12**	2,964	3,974
1944-45	6,324	9,519	**1978-79**	10,541	16,840	**2012-13**	12,239	17,860
1945-46	5,405	11,863	**1979-80**	8,966	10,041			
1946-47	6,904	13,008	**1980-81**	8,579	9,444			

Source: Own work.

The *Water flows in Tortosa* and *Water flows plus water consumption in Tortosa* series are shown in Figures 4.1 and 4.2 respectively. The *Water flows plus water consumption in Tortosa* series was obtained from *Water flows in Tortosa* and the consumption increase in the basin following Sánchez-Chóliz (2005 [160]). As annual consumption is almost constant until 1953–54, we estimate it at 2,666 hm^3 per year and we increase water consumption over these years by this figure. In addition, as the annual increase from 1953–54 is almost constant, we increase water consumption from 1954–55 in 2,666 hm^3 plus cumulative increases of 63 hm^3 per year for the sake of simplicity.

Figures 4.1 and 4.2 show a clear declining trend in the water supply. Five peaks are also observable in the periods 1914–15, 1935-36, 1959–60, 1987-88, and 2012–13, allowing a reasonable conjecture of four separate cycles. The time unit in these periods is the hydrological year which, in Spain, runs from 1 October to 30 September of the following year. In Figures 4.3 and 4.4, we adjust each cycle by a function of the following type: $y(t) = a \cdot (t - t_{initial})^{\beta} \cdot (t - t_{final})^{\delta}$. This allows us to observe that the first cycle could last until 1935–36, peaking in 1914–15. This cycle displays a convex curvature and a decreasing trend. The second cycle is runs from 1935-36 to 1959-60 and includes the lowest value for the period from 1948–49. Again, the curvature is convex. The third cycle extends from 1959-60 to 1987-88, again displaying convex curvature and a sharply declining trend. The fourth cycle would last until 2012-13. It too displays a convex curvature but the trend is more constant and even slightly upward (see Figure 4.4).

Observation of the irrigated area (see Table 4.2), meanwhile, points to several key ideas. First, the irrigated area of the Ebro basin around 1916 was almost a third of the total area in Spain, but the proportion drops slowly over the course of the twentieth century. Second, this area was two thirds greater in the 1990s than in 1916. The fall in the relative proportion of irrigated land of the Ebro basin compared to the total for Spain is due to the anticipation of water policy in this region, (see Pinilla (2008 [144]) for more detail). Finally, the continuing growth in the area of irrigated land after 1956 was still relevant, though it has slowed continuously since the mid-1960s.

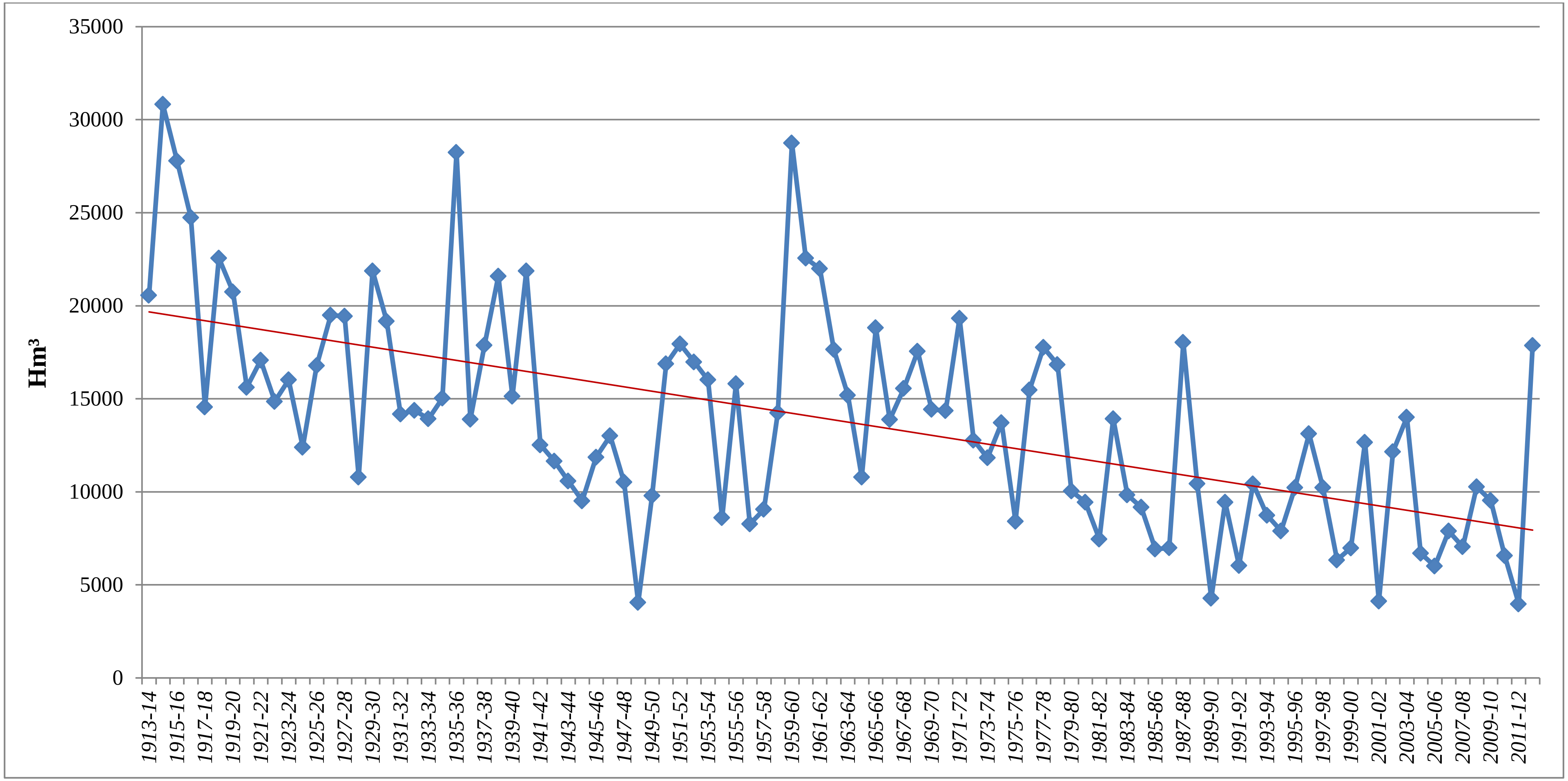
To sum up, we assume two main conjectures in this chapter. First, the trend in water resources from 1913 to the present is decreasing. Second, significant volatility is observable, revealing a great irregularity (asymmetric cycles and dry years). Meanwhile, the long cycle trend is not clear, and we have therefore refrained from any simulation. As a result, the water projection made in this chapter covers the years to 2028, based on the evolution in the region from 2001 to 2010, taking into account both the declining trend and dry years.

Table 4.2. **Evolution of the irrigated area in the Ebro basin (thousands of hectares)**

	1916	**1951-55**	**1956-60**	**1961-65**	**1966-70**	**1971-75**	**1976-80**	**1981-85**	**1986-90**	**1991-95**
Álava	0.4	2.8	2.8	2.9	2.5	2.3	1.9	1.4	5.8	6.8
Navarra	34.4	66.8	66.2	66.6	66.6	66.4	65.6	66.5	67.5	74.5
La Rioja	36.3	40.5	39.8	40.5	43	46.6	47.4	47.6	47.1	44.4
Upper Ebro	**71.1**	**110.1**	**108.8**	**110**	**112.1**	**115.3**	**114.9**	**115.5**	**120.4**	**125.7**
Huesca	63.1	84.7	86.1	104.1	122.9	137.2	152.3	163.6	177.5	180.8
Teruel	39.7	32.8	32.3	32.7	34.1	36.5	35.8	36.3	35.6	35
Zaragoza	115.7	128.4	128.6	138.9	147.8	160.5	161.5	167.5	173.6	182.5
Medium Ebro (Aragon)	**218.5**	**245.9**	**247**	**275.7**	**304.8**	**334.2**	**349.6**	**367.4**	**386.7**	**398.3**
Lérida	116.9	138.4	139.5	143.9	154.6	150.6	152.6	145.8	139.1	138.2
Tarragona	34.6	44.2	43.7	51.5	57.6	53.9	55.6	59.2	65.2	67.2
Lower Ebro (Catalonia)	**151.5**	**182.6**	**183.2**	**195.4**	**212.2**	**204.5**	**208.2**	**205**	**204.3**	**205.4**
Ebro basin	**441.1**	**538.6**	**539**	**581.1**	**629.1**	**654**	**672.7**	**687.9**	**711.4**	**729.4**
Approximated average growth	*2.50*	*0.08*	*8.42*	*9.60*	*4.98*	*3.74*	*3.04*	*4.70*	*3.60*	
Total Spain	1,366.4	1,656.3	1,770.6	1,957.9	2,175.3	2,532.1	2,739.5	2,939.5	3,132.7	3,188.7
% of Spain	*32.3*	*32.5*	*30.4*	*29.7*	*28.9*	*25.8*	*24.6*	*23.4*	*22.7*	*22.9*

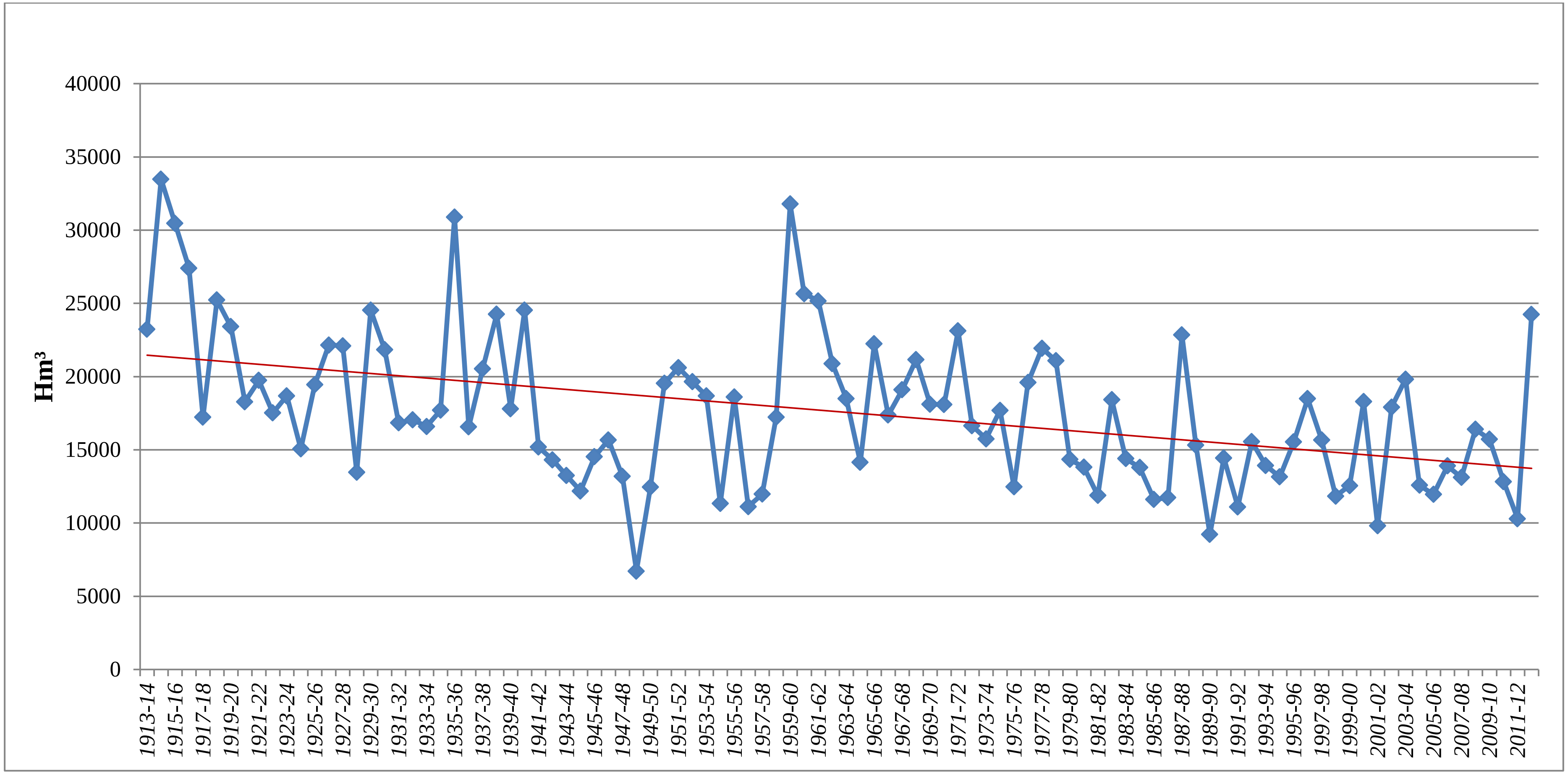
Source: Pinilla (2008 [144]).

Figure 4.1. **Water flows in Tortosa (Hm^3) 1913–2013**



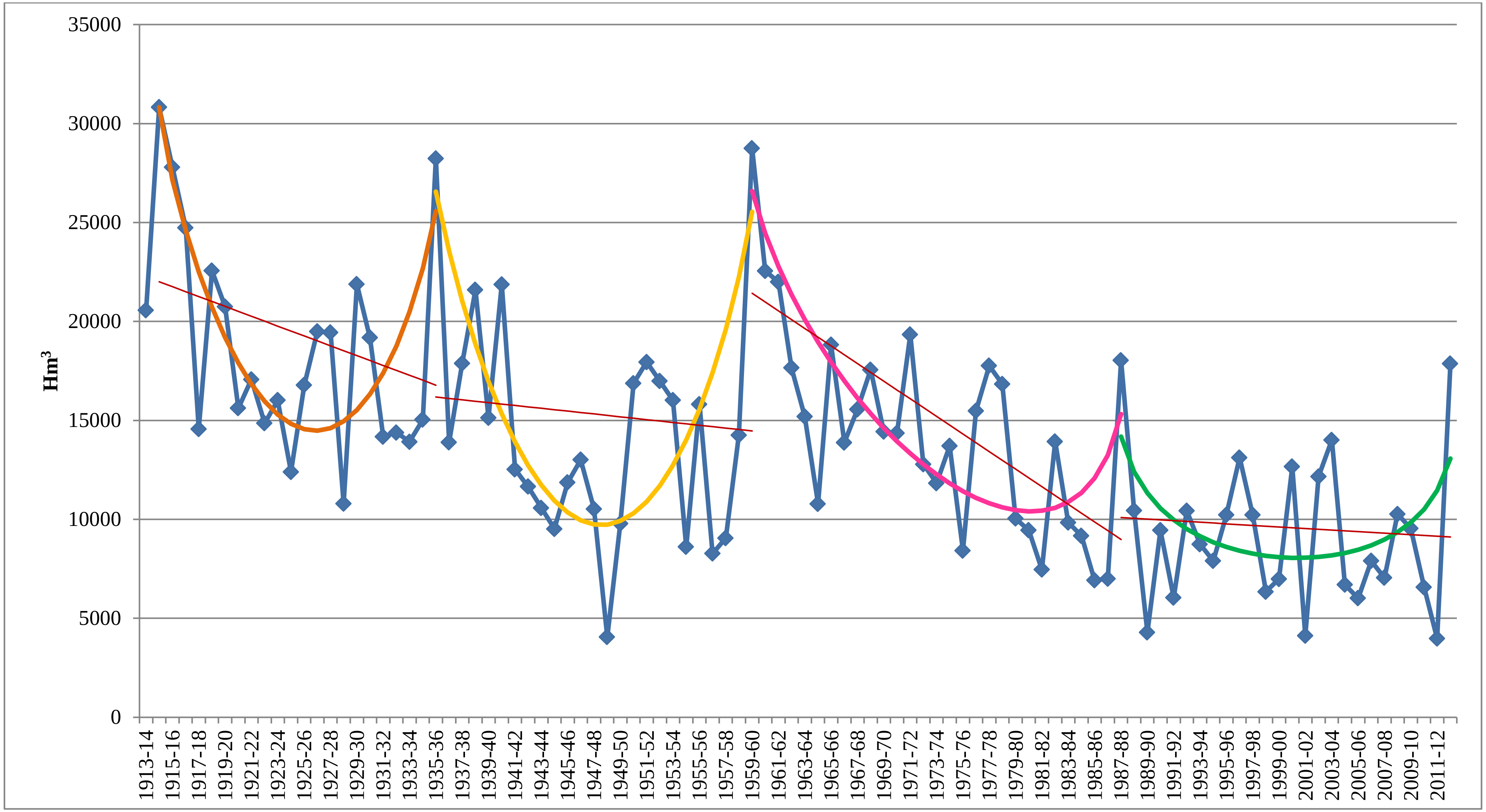
Source: Own work.

Figure 4.2. **Water flows plus water consumption in Tortosa (Hm^3) 1913–2013**



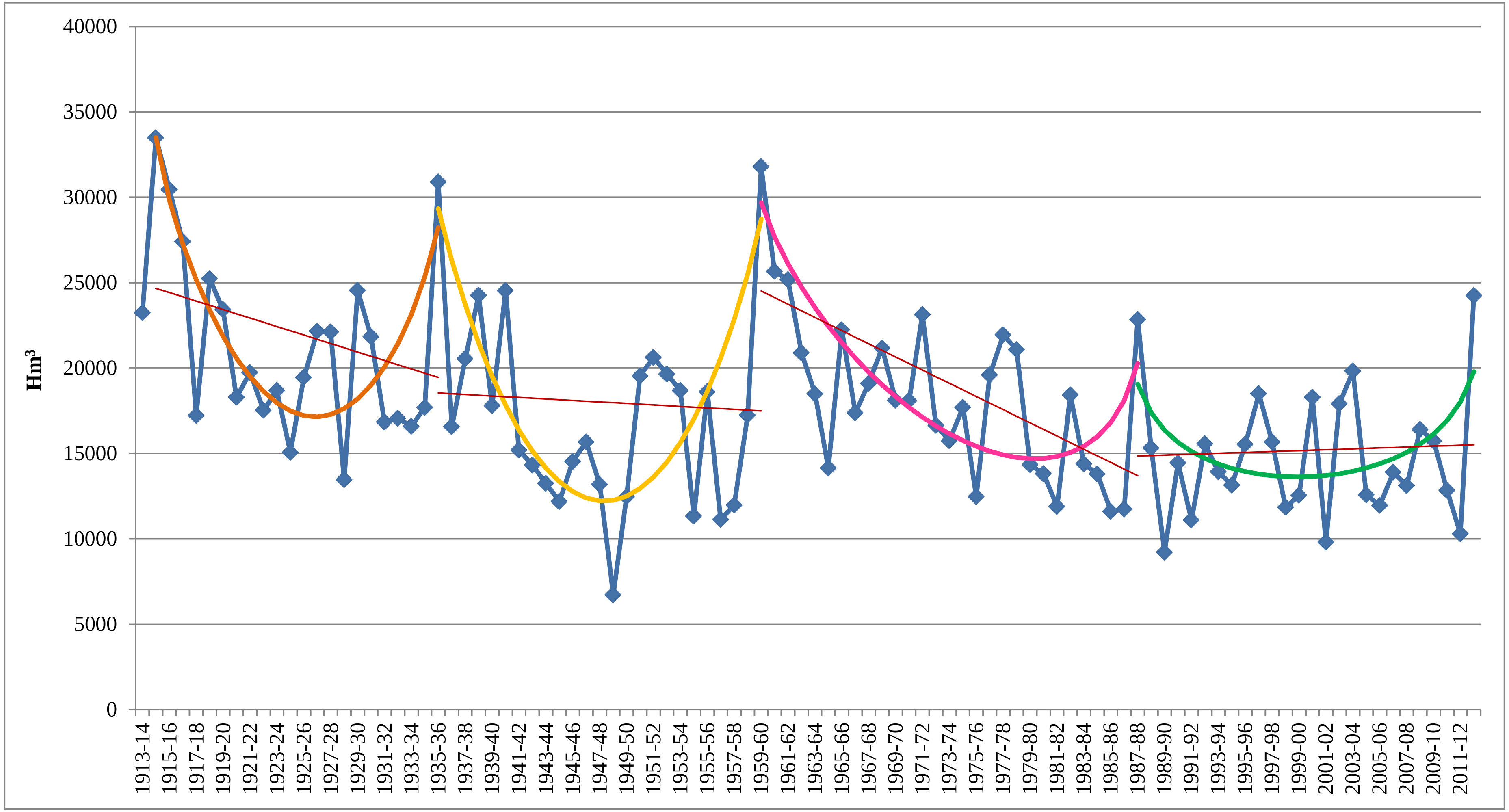
Source: Own work.

Figure 4.3. **Water flows in Tortosa (Hm^3) 1913–2013 with trends and cycles**



Source: Own work.

Figure 4.4. **Water flows plus water consumption in Tortosa (Hm^3) 1913–2013 with trends and cycles**



Source: Own work.

4.3. Technological change in irrigated agriculture

As explained in chapter 2 (section 2.2.2), the main objective of this chapter is to address technological and water management strategies to cope with future water availability including extreme events like drought. We will use a dynamic computable general equilibrium model because CGE models consider the various linkages between economic sectors and are particularly useful for the evaluation of water pricing policies (Brower and Hofkes, 2008 [36]).

The availability of advanced technology depends on the amounts earmarked to pay for investment in irrigated agriculture, and for this reason we assume that water policies can generate sufficient public revenues to cover the full costs of technology adoption. As explained in chapter 2, four alternatives are provided in the model for technological upgrades in the model, beginning with the technical change in infrastructure, transforming non-irrigated into irrigated land and thereby extending the area watered. This improvement has played a decisive role in Spanish agriculture, especially since the 1960s. We then go on to consider the use of factors. The effects of gains in irrigation water efficiency are observable because irrigated agriculture accounts for more than 80% of water uses in the Ebro basin. Thirdly, we focus on the improvements associated with the learning in farmers' use of irrigated land. This analysis allows observation of effects on cropping patterns. Finally, technical change takes productivity gains into account, reflecting farmers' reactions to increasing costs and higher productivity gains. Note that these productivity gains depend on multiple factors like irrigation know-how, agricultural research and product marketing.

Aside from technological change, the institutional framework also plays an essential role in relation to water constraints. Agriculture is the largest consumer of water, and the price paid for this resource has long been lower than its cost. In this regard, we also consider strategies which combine pricing water for irrigation and improved technology.

In this context, we are interested in answering the following questions with regard to policy options. (1) Is it possible to achieve a growth path in the face of future water constraints through strategies combining technical progress in an economy with limited natural resources? (2) What form should technological change take in irrigated agriculture? (3) Could pricing water for irrigation play a decisive role in a context of water scarcity?

4.3.1. Description of scenarios

As explained above, our strategies focus on two main assumptions. Firstly, they are designed to include technological change to tackle future water constraints, and secondly they take into account WFD targets (full recovery of water services costs) to combine pricing water for irrigation and improved technology.

We use a benchmark scenario and the seven scenarios described below to achieve our objectives. The benchmark scenario is a steady state scenario with a 2028 time horizon in which the economy is assumed to be on a balanced growth path (i.e. production factors grow at the same rate without resource constraints). The other scenarios are designed to assess the impacts of water scarcity. An annual 25% markup is applied to water consumption costs by the new agent (*Farmer*) and to receipts earmarked to pay for each technological change, as explained in chapter 2 (section 2.4.8). In the baseline year, this total payment is similar to the amount that covers the modernization of general networks and one and a half times the tax paid by direct users to the Spanish Government (see Cazcarro *et al.*, 2011a [44]). The scenarios used in the analysis are as follows:

- **Scenario 1**: The actual evolution of the irrigation water supply in Huesca province in recent years (2002-2010) is used to make a water forecast over two periods until 2028: 2011-2019 and 2020-2028. The evolution of the water supply follows a slightly downward trend and includes some drought years. In particular, we again simulate the irregular evolution observed in the period 2002-2010 for the other two periods (2011-2019 and 2020-2028) (Figure D1, Appendix D). [43] No growth rate is applied to land, as this factor is subject to long-term limits on expansion. This scenario allows us to observe adjustments between non-irrigated and irrigated land in the face of reductions in water availability without technical changes affecting crops or land allocation.

The following scenarios assume the framework of Scenario 1 and include additional technological changes:

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[43] The trend followed by water for industrial uses is completely different, even increasing in drought years. In this light, we consider only irrigation water uses. However, industrial water represents only a small share of total uses, and its exclusion therefore does not significantly change our results.

- **Scenario 2**: This scenario assumes the extension of irrigated land by transforming non-irrigated into irrigated land, which is the first of the technological improvements explained above. This scenario mirrors the policy of extending the area of irrigated land followed in Spain since the 1960s.
- **Scenario 3:** Irrigation water efficiency is assumed to follow the Gompertz function. In other words, the scenario represents the second technological upgrade explained in section 2.4.8 of chapter 2.
- **Scenario 4:** This scenario models improvements in the use of irrigated land. It implies learning in the use of irrigated land and the appropriate crop patterns.
- **Scenario 5:** This scenario assumes productivity gains based on the fourth kind of technological improvements.
- **Scenario 6:** Mixed technology: elements from Scenarios 3, 4 and 5 are included. The total payment includes the 25% markup, and one third of the amounts collected is earmarked for each technological improvement.
- **Scenario 7:** We include a structuralist approach in the model used in Scenario 6 to control the evolution of irrigation water prices in line with the WFD. Scenario 7 is thus based on Scenario 6 but assuming increasing prices. We assess different growth paths for irrigation water prices, comprising a linear water pricing trend, a three-tiered water pricing trend (the average price for each period), and a fixed high water price.[44] The main aim is to observe whether an environmental policy can be reinforced by an appropriate water pricing policy.

4.3.2. Results

This subsection presents the results of our simulations. We begin with the results of Scenario 1, which is designed to reflect the current situation. We then go on to describe the results obtained including technological improvements, both separately (Scenarios 2, 3, 4 and 5) and simultaneously (Scenarios 6 and 7). As the assumed

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[44] These prices are based on the results on water prices obtained from Scenario 6. The linear water pricing trend is the linear trend for these results. The three-tier water pricing trend uses the average price in each period for all years of each period (they are 1.20, 1.73 and 2.55). Finally, the fixed high price uses the average price of the third period for all years (it is. 2.55). See Table 4.6.

evolution in the model of the water supply is irregular but cyclical, we present the average results for the first period (2002-2010), the second period (2011-2019) and the third period (2020-2028). Finally, we examine sector level results. Annual results are available in Appendix D to section 4.3.3 of this chapter.

4.3.2.1. Scenario 1: Natural resources constraints

Scenario 1 reflects the downward trend in the water supply without technological improvements. As expected, Table 4.3 presents negative impacts on average in each period with falls in macroeconomic results in comparison with the benchmark scenario. These negative economic impacts are generally small, but they are also increasing and are greater in the third period. We may recall here that irrigated agriculture accounts for no more than 3.32% of total output from the economy in the calibration year. The largest negative impact in total production occurs in the third period, which displays an impact of 1.23%[45]. In line with the results described in the literature, this could be due to lost productivity in irrigated industries when there is no way of obtaining more water either from the markets or from institutional supply (see Berrittella *et al*., 2007 [24]). Table D1 in the Appendix D shows that the fall (from 2002 to 2028) is not relevant (65.70% of change compared with 67.77% in the benchmark scenario) although it is larger in some years of the third period such as in 2023, when the fall is 1.81%.

Meanwhile, large variations are observed in the irrigation water price, which increases on average by 39% in the first period (2002-2010), 109% in the second period (2011-2019) and 210% in the third period (2021-2030). The standard deviation of the irrigation water price is very large, reflecting significant variations between years as a consequence of the irregular evolution of water supplies.

Table 4.3 shows land allocation. The downward trend in the water supply leads to a reduction in the area of irrigated land and an expansion of non-irrigated land, both over time and in drought years (see Tables D9 and D10 in Appendix D). Meanwhile, the irrigated land given over to Cereals and legumes, which were the main crops in this region, shrinks. These crops accounted for around 62% of the total irrigated land in the calibration year. We may imagine that the area of irrigated land given over to Cereals and legumes would naturally shrink as farmers switch away from planting maize and

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[45] These results are an average for each period, and the individual results in drought years are not small, see Table D1 in Appendix D.

rice, which need a lot of water. Increases in the land under cultivation are observable in Fruit and vegetables and Olives and vineyards. These crops accounted for 7% and 1% respectively in the calibration year. Interestingly, the total area of farmland in fact also shrinks in spite of the increase in the area of non-irrigated land, reflecting the abandonment of fields by farmers (see Table 4.3, Figure D2 and Tables D8, D9 and D10 in Appendix D, reflecting the change between 2002 and 2028).

Table 4.3. **Results for Scenario 1** (*Average variation in each period compared to benchmark scenario*)

Period		**2002-2010**	**2011-2019**	**2020-2028**
Total production		-0.29	-0.74	-1.23
Total Private consumption		-0.02	-0.07	-0.23
Capital investment		-0.01	-0.06	-0.20
Total exports		-0.39	-0.99	-1.59
Total imports		-0.28	-0.75	-1.27
Total production, Irrigated agriculture		-8.75	-21.56	-33.99
Total production, Rest of farming		-4.61	-12.65	-21.79
Total production, Industrial sectors		0.42	1.11	1.82
Total production, Services		0.03	0.07	0.08
Total land		-0.12	-0.30	-0.66
Total non-irrigated land		1.14	2.51	3.87
Total irrigated land		-0.77	-1.76	-3.01
Irrigated land	Cereals and legumes	-1.60	-4.95	-10.68
	Industrial crops	-0.28	1.83	8.29
	Fruit and vegetables	3.41	8.41	12.11
	Olives and vineyards	6.60	17.64	30.71
Prices (baseline index = 1.00)				
User cost of irrigation water factor		1.39	2.09	3.10
Standard annual deviation of irrigation water prices (%)		*46.93*	*64.50*	*87.09*

Source: Own work.

Table 4.3 also shows the results for production in the main sectors. The sharpest falls are found in the output from irrigated agriculture (8.75% on average in the first period, 21.56% in the second period and 33.99% in the third period). See also Table D4 in Appendix D. This result is followed by shrinking output in the rest of the farm sector, which of course depends on irrigated agriculture. The slight increase in the production of the industrial and services sectors is linked to substitution effects between capital and water in the face of water constraints.

Finally, observation of trade results (see Tables D15-D18 in Appendix D) reveals a fall in total exports. We may recall here that these results are compared to the benchmark scenario, which displays an increasing trend from 2002 to 2028. The decline is due mainly to falls in the output of irrigated agriculture sectors (in descending order Cereals and legumes, Industrial crops, Fruit and vegetables and Olives and vineyards), Agri-food industry and Livestock. These negative results are greater in the second and third periods. Total imports also shrink although these falls are slightly lower. However, Table D18 in Appendix D reveals increases in imports in some irrigated agriculture sectors (mainly Industrial crops).

4.3.2.2. Transforming non-irrigated into irrigated land (Scenario 2)

Table 4.4 shows the effects of transforming land despite the downward trend in the water supply (Scenario 1). Figures in italics show the differences with Scenario 1 (Table 4.3) in order to reveal the gains achieve through this technological change.

Table 4.4. **Results for Scenario 2**

(*Average variation in each period compared to benchmark scenario and differences with Scenario 1*)

	Period	**2002-2010**		**2011-2019**		**2020-2028**	
	Total production	-0.06	*0.22*	-0.30	*0.44*	-0.60	*0.63*
	Total Private consumption	-0.83	*-0.81*	-0.58	*-0.50*	-0.44	*-0.21*
	Capital investment	2.46	*2.48*	2.72	*2.78*	2.86	*3.06*
	Total exports	-0.44	*0.00*	-0.82	*0.21*	-1.24	*0.39*
	Total imports	-0.33	*-0.02*	-0.53	*0.20*	-0.82	*0.37*
	Total production, Irrigated agriculture	-8.49	*0.26*	-20.90	*0.66*	-33.16	*0.82*
	Total production, Rest of farming	-4.10	*0.51*	-11.38	*1.28*	-20.02	*1.77*
	Total production, Industrial sectors	1.02	*0.59*	1.88	*0.77*	2.77	*0.95*
	Total production, Services	-0.26	*-0.29*	-0.03	*-0.10*	0.16	*0.08*
	Total land	1.45	*1.56*	1.23	*1.53*	0.77	*1.43*
	Total non-irrigated land	-0.91	*-2.05*	0.89	*-1.62*	2.66	*-1.21*
	Total irrigated land	2.67	*3.45*	1.40	*3.17*	-0.21	*2.81*
Irrigated land	Cereals and legumes	1.79	*3.39*	-2.09	*2.86*	-8.61	*2,07*
	Industrial crops	3.19	*3.47*	5.33	*3.50*	12.16	*3,86*
	Fruit and vegetables	7.25	*3.84*	12.75	*4.34*	16.67	*4,56*
	Olives and vineyards	10.06	*3.45*	21.51	*3.87*	34.98	*4,27*
	Prices (baseline index = 1.00)						
	User cost of irrigation water factor	1.40		2.13		3.18	
	Standard annual deviation of irrigation water prices (%)	*47.03*		*65.31*		*88.76*	

Source: Own work.

Despite investments to expand irrigated land, the area of non-irrigated land is barely reduced and even increases in the second and third periods, while irrigated land shrinks in the third period. Therefore, this measure only works in the first period, but not over time (second and third periods). If we compare this outcome with the results obtained without technological change (Scenario 1), the production of irrigated agriculture hardly improves. This table clearly shows the strong sensitivity of the system to water availability, and it suggests that the extension of irrigated land is a doubtful alternative in the presence of water constraints. This confirms recent studies which recommend encouraging irrigated land consolidation instead of expansion, against the trend followed in Spain since the 1960s.

4.3.2.3. Results for each technical change (Scenarios 3, 4 and 5)

As the objective is to analyze the effects produced by the technological changes, Table 4.5 also reflects differences with Scenario 1 (Table 4.3) in italics. Appendix D shows annual results compared with the benchmark scenario.

Gains in water efficiency (Scenario 3, “*Water”*) are able to mitigate falls in output from irrigated agriculture, and therefore to reduce negative impacts on total production in the economy. These gains also lead to more efficient land use allocation by providing a stimulus to grow crops on irrigated land instead of non-irrigated land, mitigating the contraction of irrigated land. The reduction in land earmarked for Cereals and legumes is smaller in comparison with Scenario 1 (no technological change), and the increases in other irrigated crops are smaller. We may suppose that the higher availability of water after this improvement allows farmers to plant maize, rice, and alfalfa, all of which are thirsty crops included in the Cereals and legumes group.

Improvements in the efficiency of land use (Scenario 4, *“Land-crops”*) have some effect in reducing negative impacts, although this technological change is less effective compared with the other two upgrades, in particular in the second and third periods. Specifically, irrigated agriculture production hardly improves despite the switch in land use towards Fruit and vegetables and Olives and vineyards. In any event, this improvement shows that land use efficiency reduces non-irrigated instead of irrigated land.

Table 4.5. **Results for each technological improvement**

(*Average variation in each period compared to benchmark scenario and differences with Scenario 1*)

	Period	**2002-2010**						**2011-2019**						**2020-2028**					
	Technological improvement	**Water (Sce3)**		**Land-crops (Sce4)**		**Prod. Gains (Sce5)**		**Water (Sce3)**		**Land-crops (Sce4)**		**Prod. Gains (Sce5)**		**Water (Sce3)**		**Land-crops (Sce4)**		**Prod. Gains (Sce5)**	
	Total production	-0.07	*0.22*	-0.07	*0.22*	1.08	*1.37*	-0.21	*0.53*	-0.30	*0.44*	1.29	*2.03*	-0.45	*0.78*	-0.60	*0.63*	1.54	*2.77*
	Total Private consumption	-0.86	*-0.84*	-0.82	*-0.81*	-0.78	*-0.76*	-0.68	*-0.61*	-0.57	*-0.50*	-0.50	*-0.43*	-0.57	*-0.35*	-0.44	*-0.21*	-0.34	*-0.12*
	Capital investment	1.39	*1.41*	2.48	*2.50*	2.53	*2.54*	1.55	*1.61*	2.74	*2.80*	2.81	*2.88*	1.66	*1.86*	2.45	*3.06*	2.98	*3.18*
	Total exports	-0.26	*0.18*	-0.45	*-0.01*	-0.13	*0.31*	-0.51	*0.53*	-0.83	*0.20*	-0.53	*0.51*	-0.87	*0.76*	-1.25	*0.38*	-0.96	*0.67*
	Total imports	-0.16	*0.15*	-0.33	*-0.03*	-0.09	*0.22*	-0.27	*0.45*	-0.53	*0.19*	-0.27	*0.45*	-0.50	*0.68*	-0.82	*0.36*	-0.56	*0.63*
	Total production, Irrigated agriculture	-5.13	*3.62*	-8.51	*0.24*	-1.40	*7.35*	-12.32	*9.24*	-20.91	*0.65*	-14.87	*6.69*	-21.65	*12.34*	-33.17	*0.82*	-28.29	*5.70*
	Total production, Rest of farming	-3.57	*1.04*	-4.29	*0.31*	-3.08	*1.53*	-8.24	*4.41*	-11.61	*1.04*	-10.22	*2.43*	-14.56	*7.23*	-20.28	*1.51*	-18.78	*3.01*
	Total production, Industrial sectors	0.78	*0.36*	1.03	*0.61*	0.65	*0.23*	1.31	*0.20*	1.89	*0.79*	1.56	*0.45*	1.94	*0.12*	2.78	*0.97*	2.50	*0.68*
	Total production, Services	-0.31	*-0.33*	-0.26	*-0.28*	-0.20	*-0.22*	-0.16	*-0.23*	-0.03	*-0.10*	0.05	*-0.02*	-0.03	*-0.11*	0.16	*0.08*	0.25	*0.17*
	Total land	-0.08	*0.04*	-0.24	*-0.12*	-0.12	*-0.01*	-0.10	*0.20*	-0.50	*-0.20*	-0.34	*-0.04*	-0.17	*0.48*	-1.04	*-0.38*	-0.75	*-0.10*
	Total non-irrigated land	0.54	*-0.60*	-2.60	*-3.74*	1.18	*0.04*	0.92	*-1.59*	-1.23	*-3.74*	2.69	*0.18*	1.67	*-2.19*	0.28	*-3.59*	4.12	*0.25*
	Total irrigated land	-0.40	*0.37*	0.98	*1.76*	-0.81	*-0.03*	-0.63	*1.13*	-0.12	*1.65*	-1.91	*-0.15*	-1.14	*1.88*	-1.73	*1.29*	-3.29	*-0.28*
Irrigated land	Cereals and legumes	-0.96	*0.64*	-0.02	*1.58*	-2.60	*-1.00*	-2.19	*2.76*	-3.69	*1.26*	-6.02	*-1.07*	-4.95	*5.73*	-10.51	*0.17*	-11.97	*-1.29*
	Industrial crops	-0.08	*0.20*	1.58	*1.86*	-0.40	*-0.12*	0.46	*-1.38*	3.93	*2.10*	1.36	*-0.48*	3.17	*-5.12*	11.35	*3.06*	7.88	*-0.41*
	Fruit and vegetables	2.60	*-0.81*	6.16	*2.75*	12.40	*8.99*	6.91	*-1.50*	11.41	*3.00*	17.85	*9.44*	11.36	*-0.75*	15.37	*3.26*	21.35	*9.24*
	Olives and vineyards	3.97	*-2.63*	9.26	*2.65*	4.42	*-2.18*	10.57	*-7.07*	20.19	*2.54*	15.60	*-2.04*	19.67	*-11.04*	34.32	*3.60*	28.72	*-1.99*
	Prices (baseline index = 1.00)																		
	User cost of irrigation water factor	1.32		1.45		1.45		1.90		2.15		2.20		2.79		3.32		3.29	
	Standard annual deviation of irrigation water prices (%)	*45.15*		*47.03*		*48.55*		*62.66*		*65.32*		*67.35*		*87.03*		*88.77*		*91.09*	

Source: Own work.

Finally, productivity gains (Scenario 5, *“Prod. Gains”*) also boost the production of irrigated agriculture, although this improvement loses effectiveness over time. Total irrigated land shrinks as a result of reductions in the land set aside for Cereals and legumes, while irrigated land earmarked to grow the most profitable crops (Fruit and vegetables) increases. This improvement shows positive results in the output of the economy as a whole in all periods.

4.3.2.4. Results for mixed technology strategies (Scenario 6)

The results for Scenario 6 show the effects of a strategy designed to upgrade technology in irrigated agriculture including the previous three technological improvements (Scenarios 3, 4 and 5). Given its doubtful benefits, the alternative of Scenario 2 was not included in Scenario 6. This scenario may be more realistic because technical changes are not isolated effects (irrigation technology, changes in cropping, market and economic changes all exist in a state of permanent co-evolution). Table 4.6 again shows points of difference between Scenario 6 and Scenario 1 in italics.

As can be seen, Scenario 6 improves results in both the production of irrigated agriculture and in total production, eliminating the falls output in the first period and significantly reducing them in the third period. Falls in exports and imports are also reduced. As private consumption is a function of disposable income, any decrease in the latter (as a result of higher markups in this case) will also depress consumption (see also Table D2 in Appendix D). Land use changes show a clear shift towards irrigated land instead of non-irrigated land.

Based on the comparison of Tables 4.3 and 4.6, however, we observe that reducing negative impacts on the economy becomes more difficult as time goes by due to larger water constraints. Thus, a water policy capable of reversing the dramatic trend in irrigated agriculture is likely to require a permanent improvement in irrigation water efficiency through modernization, encouraging farmers to make good use of the opportunities available to achieve productivity gains and optimize their use of resources after the investment in irrigation in order to focus on the most profitable crops. In any event, physical and environmental limits cannot be ignored, because technology and management will not provide a panacea in the medium term.

To sum up, a strategy based on improving the technologies used in irrigated agriculture in the face of future water constraints would succeed in mitigating impacts on the economy as a whole and reversing the long-term trend in irrigated agriculture. Furthermore, the evolution of cropping patterns would shift towards more profitable crops such as Fruit and vegetables, with additional improvements in Cereals and legumes. Moreover, a combination of technology improvements is perhaps the only way to achieve a growth path for irrigated agriculture and, consequently in the economy as a whole in the face of severe water constraints.

Table 4.6. **Results for Scenario 6**

(*Average variation in each period compared to benchmark scenario and differences with Scenario 1*)

	Period	**2002-2010**		**2011-2019**		**2011-2019**	
	Total production	0.15	*0.43*	0.08	*0.82*	-0.10	*1.13*
	Total Private consumption	-0.77	*-0.75*	-0.48	*-0.41*	-0.27	*-0.04*
	Capital investment	2.17	*2.19*	2.44	*2.50*	2.65	*2.85*
	Total exports	-0.04	*0.40*	-0.22	*0.81*	-0.53	*1.10*
	Total imports	-0.02	*0.28*	-0.04	*0.68*	-0.19	*1.00*
	Total production, Irrigated agriculture	2.54	*11.29*	-5.06	*16.50*	-15.13	*18.86*
	Total production, Rest of farming	-2.32	*2.28*	-6.69	*5.97*	-12.76	*9.03*
	Total production, Industrial sectors	0.54	*0.12*	1.15	*0.04*	1.88	*0.06*
	Total production, Services	-0.25	*-0.28*	-0.04	*-0.11*	0.16	*0.08*
	Total land	-0.13	*-0.02*	-0.17	*0.13*	-0.29	*0.37*
	Total non-irrigated land	-3.42	*-4.56*	-2.89	*-5.40*	-2.05	*-5.91*
	Total irrigated land	1.58	*2.35*	1.24	*3.00*	0.63	*3.64*
Irrigated land	Cereals and legumes	-0.01	*1.59*	-1.26	*3.69*	-4.10	*6.59*
	Industrial crops	1.95	*2.23*	2.08	*0.25*	4.55	*-3.74*
	Fruit and vegetables	13.47	*10.06*	18.20	*9.79*	22.79	*10.68*
	Olives and vineyards	3.85	*-2.76*	10.55	*-7.09*	19.76	*-10.95*
	Prices (baseline index = 1.00)						
	User cost of irrigation water factor	1.20		1.73		2.55	
	Standard annual deviation of irrigation water prices (%)	*40.55*		*56.49*		*78.51*	

Source: Own work.

4.3.2.5. Results for strategies which combine water pricing and improved technology (Scenario 7)

Finally, Scenario 7 aims, in conjunction with the three improved technologies of Scenario 6, to manage the evolution of irrigation water prices avoiding the price volatility inherent in Scenario 6. This scenario focuses on EU targets requiring the recovery of water costs. It assumes that a high water price will be needed to recover costs in the case of water constraints. We assume three alternative price evolutions. The results are shown in Table 4.7 in comparison with the results of Scenario 6 (figures in italics) in order to observe advantages and disadvantages of applying water pricing policies.

To begin with, a gradual rise (*“Linear”*) in irrigation water prices following the trend observed in Scenario 6 improves irrigation agriculture production results in the second and third periods by expanding the most profitable crops (Fruit and vegetables) in comparison with Scenario 6. Results in total production are, however, slightly worse compared with Scenario 6.

Secondly, a three-tiered trend in irrigation water prices (*“Tiered”*, average price of each period in Scenario 6) again provides farmers with an incentive to put their resources into the most profitable crops, like Fruit and vegetables. This measure performs is slightly worse than the “*Linear*” alternative for total production, but it is better for irrigated agriculture production and, interestingly, for Fruit and vegetables.

Thirdly, a sharp rise in irrigation water prices from the outset (“*High*”, average price of the third period in Scenario 6) based on a policy designed to ensure that the price remains constant and very high again improves results in irrigated agriculture. However, an excess price hike leads to substantial falls in consumption and output caused by sharp contraction in other farming operations and industry, mainly in the first and second periods.

A clear observation is that the three irrigation water price paths result in optimal use of the land factor. This is due to the substitution process between irrigated agriculture accounts, stimulating profitable cropping patterns and improving the use of factors towards irrigated crops, mainly Fruit and vegetables.

To sum up, Scenario 7, which involves not only technical progress but also irrigation water price planning to avoid price volatility, improves results in irrigated agriculture sectors compared with Scenario 6. However, results in total production are slightly worse. The main conclusion of this scenario is that combining water pricing and improved technology could provide the tools to handle water uncertainties and shortages.

In this scenario, a gradual rise in irrigation water prices both following the linear trend and a three-tiered trend could be a reasonable option to obtain improvements in irrigated agriculture production. These measures avoid negative results in other sectors and in the economy as a whole, unlike a sudden hike to a high water price.

Table 4.7. **Results for Scenario 7**

(*Average variation in each period compared to benchmark scenario and differences with Scenario 6*)

	Period	**2002-2010**						**2011-2019**						**2020-2028**					
		Linear		Tiered		High		Linear		Tiered		High		Linear		Tiered		High	
	Total production	0.08	*-0.07*	0.05	*-0.09*	-1.11	*-1.26*	0.01	*-0.07*	-0.02	*-0.10*	-0.49	*-0.56*	-0.16	*-0.06*	-0.19	*-0.09*	-0.39	*-0.29*
	Total Private consumption	-0.77	*0.00*	-0.99	*-0.22*	-3.69	*-2.92*	-0.68	*-0.20*	-0.71	*-0.22*	-1.85	*-1.36*	-0.40	*-0.13*	-0.47	*-0.21*	-0.76	*-0.50*
	Capital investment	2.12	*-0.05*	2.01	*-0.17*	0.16	*-2.02*	2.30	*-0.14*	2.26	*-0.17*	1.52	*-0.92*	2.55	*-0.11*	2.50	*-0.15*	2.24	*-0.41*
	Total exports	-0.04	*-0.07*	-0.02	*0.02*	0.11	*0.15*	-0.22	*0.04*	-0.22	*0.01*	-0.25	*-0.03*	-0.53	*0.00*	-0.54	*0.00*	-0.74	*-0.20*
	Total imports	-0.13	*-0.06*	-0.16	*-0.14*	-1.60	*-1.57*	-0.55	*-0.11*	-0.19	*-0.14*	-0.84	*-0.79*	-1.02	*-0.08*	-0.32	*-0.13*	-0.56	*-0.37*
	Total production, Irrigated agriculture	-0.66	*-3.20*	11.83	*9.29*	123.90	*121.37*	4.08	*9.14*	3.71	*8.77*	46.30	*51.36*	-10.31	*4.82*	-7.77	*7.36*	-7.43	*7.70*
	Total production, Rest of farming	-3.02	*-0.69*	-4.01	*-1.69*	-23.09	*-20.77*	-8.03	*-1.35*	-8.27	*-1.59*	-14.89	*-8.20*	-13.67	*-0.91*	-14.09	*-1.33*	-14.83	*-2.06*
	Total production, Industrial sectors	0.67	*0.13*	0.04	*-0.50*	-6.14	*-6.69*	0.67	*-0.48*	0.66	*-0.49*	-1.74	*-2.88*	1.61	*-0.27*	1.46	*-0.41*	1.27	*-0.61*
	Total production, Services	-0.23	*0.02*	-0.40	*-0.16*	-2.34	*-2.09*	-0.18	*-0.14*	-0.20	*-0.16*	-1.00	*-0.96*	0.06	*-0.09*	0.01	*-0.14*	-0.17	*-0.32*
	Total land	-0.29	*-0.15*	-0.24	*-0.11*	-0.68	*-0.55*	-0.25	*-0.08*	-0.27	*-0.10*	-0.25	*-0.07*	-0.37	*-0.08*	-0.36	*-0.08*	-0.35	*-0.06*
	Total non-irrigated land	-3.18	*0.23*	-3.88	*-0.47*	-3.18	*0.23*	-3.33	*-0.44*	-3.30	*-0.41*	-3.33	*-0.44*	-2.27	*-0.22*	-2.37	*-0.32*	-2.27	*-0.22*
	Total irrigated land	1.22	*-0.36*	1.65	*0.07*	3.71	*2.13*	1.35	*0.11*	1.31	*0.07*	2.35	*1.11*	0.62	*-0.01*	0.68	*0.05*	0.77	*0.14*
Irrigated land	Cereals and legumes	0.58	*0.58*	-1.09	*-1.09*	-17.79	*-17.79*	-2.48	*-1.22*	-2.32	*-1.06*	-9.27	*-8.01*	-4.68	*-0.59*	-5.09	*-0.99*	-5.03	*-0.93*
	Industrial crops	1.06	*-0.89*	0.91	*-1.04*	-12.03	*-13.98*	1.07	*-1.01*	0.88	*-1.20*	-2.80	*-4.88*	3.64	*-0.91*	3.38	*-1.17*	3.25	*-1.31*
	Fruit and vegetables	7.11	*-6.36*	28.34	*14.87*	256.79	*243.32*	34.55	*16.36*	33.43	*15.23*	123.96	*105.77*	31.65	*8.86*	37.06	*14.27*	38.38	*15.60*
	Olives and vineyards	4.20	*0.35*	2.99	*-0.86*	-7.04	*-10.89*	9.69	*-0.86*	9.71	*-0.84*	5.82	*-4.73*	19.29	*-0.47*	19.06	*-0.70*	18.77	*-1.00*
	Prices (baseline index = 1.00)																		
	User cost of irrigation water factor	1.05		1.20		2.55		1.78		1.72		2.55		2.50		2.55		2.55	
	Standard deviation of irrigation water prices (%)	*22.10*		*0.00*		*0.00*		*22.11*		*0.00*		*0.00*		*22.01*		*0.00*		*0.00*	

Source: Own work.

4.3.2.6. Sector results

Differences between sector output results are significant, as shown in Table 4.8. In order to simplify, we show only the results in Scenarios 1, 6 and 7. Some results of scenarios for each separate improvement (Scenarios 2, 3, 4 and 5) are provided in Appendix D. The largest falls in output in Scenario 1, in descending order, are found in irrigated agriculture (specifically Cereals and legumes), Livestock, Agri-food industry and Non-irrigated agriculture. Given the relevance of irrigated agriculture sectors, detailed results are shown in Tables D11, D12, D13 and D14 of Appendix D. This is because irrigated agriculture sectors and the Livestock account for a significant share of water factor production given their high water consumption. The falls in Agri-food industry are due to the sector's dependence on irrigated agriculture. These falls are larger in the third period. In contrast, the account with the largest increase in output is Mineral products, machinery and transport material. This may be because the substitution effect between capital and water encourages greater investment in capital and machinery in the face of water constraints.

Scenario 6 reduces the falls in irrigated agriculture sectors, which even display positive results in the most profitable crops (Fruit and vegetables) in the two first periods. This scenario also reduces spillover effects in the rest of the economy, mitigating falls in Agri-food industry and Livestock even in the third period. On the other hand, positive results in industrial accounts are reduced. The scenario thus reduces differences between sectors, which are reflected in lower standard deviations.

The effects on crop production in scenario 7 are relevant. The three price alternatives have better effects on Fruit and vegetables production than Scenario 6. Specifically, Fruit and vegetables achieve larger positive output results even in the third period. Therefore, these findings again confirm that the lower price volatility achieved through a water pricing system would be likely to improve water use in irrigated agriculture.

Table 4.9 shows sector price results in each period. Taking into account the downward trend in the water supply, Scenario 1 reveals a significant rise in prices in irrigated agriculture sectors, specifically in Industrial crops and Cereals and legumes. These price rises are even larger in the following periods. They are followed by price rises in Fruit and vegetables, Livestock, Agri-food industry, Non-irrigated agriculture and Olives and vineyards.

Technological improvements in irrigated agriculture lead to lower agricultural prices as a consequence of better use of natural resources, and enhanced irrigation know-how and marketing processes, as reflected in the price results for Scenarios 6 and 7. They also reduce differences between sectors (i.e. standard deviation is reduced in the model from 1.77% in Scenario 1 to 0.89% in Scenario 6 in the first period, from 4.61% to 2.39% in the second period, and from 8.02% to 4.62% in the third period), and the resulting prices are closer to the benchmark scenario.[46] However, price rises in irrigated agriculture increase over time, although technology upgrades to some extent mitigate this effect. As we have seen, these results translate into significant changes in output volume, especially in Fruit and vegetables.

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[46] The standard deviation in Scenario 7 ("High") is higher in the first period than Scenario 1, but this result does not change the general conclusion.

Table 4.8. **Sector production** (*Average variation in each period compared to benchmark scenario*)

	2002-2010					**2011-2019**					**2020-2028**				
	Sce 1	**Sce 6**	**Sce 7**			**Sce 1**	**Sce 6**	**Sce 7**			**Sce 1**	**Sce 6**	**Sce 7**		
			Linear	Tiered	High			Linear	Tiered	High			Linear	Tiered	High
Cereals and legumes (irrigated land)	-14.74	-6.98	-6.61	-8.81	-32.33	-35.63	-20.34	-22.02	-21.97	-30.91	-53.87	-36.11	-37.00	-37.52	-37.57
Industrial crops (irrigated land)	-12.10	-3.82	-5.21	-4.73	-22.10	-27.92	-14.75	-15.44	-15.77	-20.54	-40.18	-26.37	-26.91	-27.23	-27.43
Fruit and vegetables (irrigated land)	-6.61	8.76	3.43	27.87	258.49	-17.26	3.23	21.52	21.07	107.38	-29.35	-5.82	3.82	8.90	9.63
Olives and vineyards (irrigated land)	-3.91	-0.67	-2.30	-1.22	-7.67	-10.30	-3.67	-3.64	-4.05	-4.56	-17.58	-8.33	-8.37	-8.45	-8.80
Non-irrigated agriculture	-3.41	-4.28	-4.46	-6.19	-26.07	-11.29	-10.87	-12.22	-12.42	-18.87	-19.81	-18.18	-18.88	-19.24	-19.92
Livestock	-5.14	-1.63	-2.56	-3.36	-22.56	-13.50	-5.27	-6.69	-6.96	-13.69	-23.18	-11.07	-12.06	-12.51	-13.22
Energy products	0.83	1.89	2.13	2.09	4.04	2.25	2.72	2.98	3.01	3.36	4.08	3.97	4.33	4.35	4.20
Water	-3.92	0.74	-0.71	4.66	51.30	-9.86	-2.87	1.06	0.88	18.72	-15.69	-7.56	-5.38	-4.33	-4.37
Minerals and metals	1.81	1.64	2.24	0.85	-8.43	4.68	3.61	2.90	2.97	-0.94	7.72	6.18	6.01	5.79	5.49
Minerales and non-metals products	0.19	1.50	1.59	1.54	2.18	0.54	1.74	1.88	1.89	1.92	1.04	2.10	2.35	2.35	2.23
Chemicals	1.06	-0.11	-0.04	0.27	5.22	2.66	0.56	0.86	0.90	3.05	4.26	1.55	1.65	1.79	2.06
Mineral products, machinery and transport material	6.86	0.82	3.51	-0.94	-24.12	18.21	7.11	5.04	5.56	-5.96	31.16	16.19	15.66	15.03	14.81
Agri-food industry	-4.58	-1.02	-2.59	-1.84	-11.02	-12.09	-4.54	-4.77	-5.18	-6.76	-20.66	-10.00	-10.19	-10.33	-10.74
Manufactures	0.36	-0.49	-0.49	-0.73	-3.21	0.80	-0.27	-0.24	-0.26	-0.83	1.10	0.00	0.32	0.29	0.31
Rubber, plastics and others	1.44	-0.22	0.25	-0.14	0.61	3.80	0.65	0.82	0.93	0.91	6.63	2.16	2.61	2.62	2.88
Construction and engineering	-0.09	1.74	1.70	1.65	0.68	-0.23	1.87	1.88	1.85	1.44	-0.42	1.95	2.06	2.03	1.82
Hotels and restaurants	-0.14	-0.64	-0.60	-0.84	-3.49	-0.35	-0.59	-0.49	-0.51	-1.62	-0.56	-0.60	-0.13	-0.19	-0.44
Rest of services	0.11	-0.18	-0.17	-0.32	-2.02	0.26	0.13	-0.12	-0.13	-0.83	0.36	0.42	0.11	0.07	-0.07
Standard deviation (%)	*5.17*	*3.21*	*2.90*	*7.52*	*64.93*	*12.77*	*6.91*	*9.17*	*9.19*	*28.58*	*20.13*	*12.37*	*12.78*	*13.12*	*13.24*

Source: Own work.

Table 4.9. **Sector prices** (*Average variation in each period compared to benchmark scenario*)

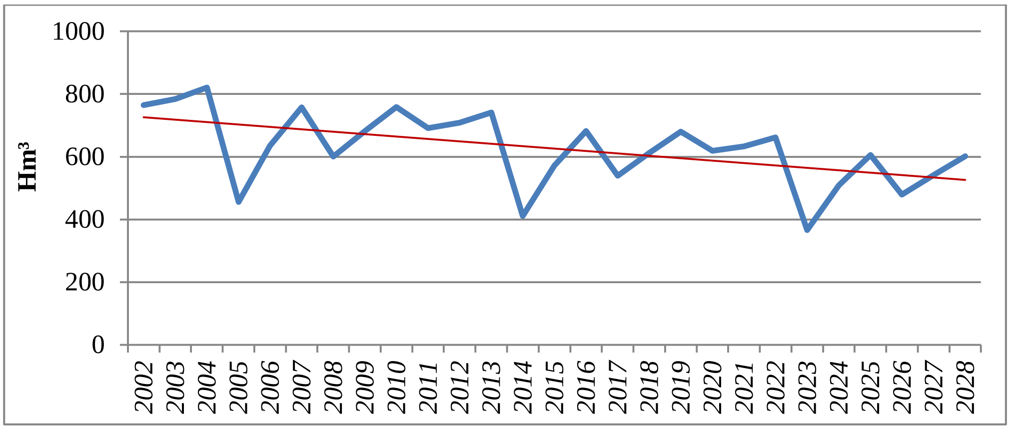
	2002-2010					**2011-2019**					**2020-2028**				
	Sce1	**Sce6**	**Sce 7**			**Sce1**	**Sce6**	**Sce 7**			**Sce1**	**Sce6**	**Sce 7**		
			Linear	Tiered	High			Linear	Tiered	High			Linear	Tiered	High
Cereals and legumes (irrigated land)	3.10	1.69	1.24	1.87	6.51	7.99	4.62	4.95	4.84	7.09	13.27	8.52	8.68	8.80	8.73
Industrial crops (irrigated land)	7.02	2.88	3.19	2.97	8.27	18.38	9.19	9.47	9.43	11.53	32.12	18.22	18.55	18.67	18.41
Fruit and vegetables (irrigated land)	0.59	-1.62	0.44	-2.89	-19.61	1.62	-1.18	-2.70	-2.31	-10.95	3.04	-0.36	-0.79	-1.26	-1.45
Olives and vineyards (irrigated land)	0.61	-0.44	0.67	-0.47	-3.44	1.67	0.05	-0.12	0.07	-2.03	3.09	0.86	1.04	0.95	0.89
Non-irrigated agriculture	-0.01	0.16	0.11	0.22	0.92	0.10	0.38	0.43	0.43	0.69	0.21	0.58	0.61	0.62	0.64
Livestock	0.09	0.06	0.01	0.14	1.37	0.24	0.10	0.21	0.20	0.75	0.47	0.18	0.26	0.29	0.32
Energy products	-0.26	-0.04	-0.12	-0.09	-0.54	-0.71	-0.25	-0.28	-0.30	-0.37	-1.26	-0.58	-0.61	-0.62	-0.63
Water	-0.22	0.05	0.01	-0.16	-2.52	-0.59	0.02	-0.15	-0.18	-1.02	-1.07	-0.14	-0.25	-0.30	-0.43
Minerals and metals	0.12	0.02	0.02	-0.21	-2.78	0.25	0.20	0.00	-0.01	-0.85	0.26	0.37	0.25	0.20	0.15
Minerales and non-metals products	-0.02	0.01	0.00	-0.05	-0.72	-0.07	0.03	-0.03	-0.03	-0.25	-0.16	0.02	-0.02	-0.04	-0.06
Chemicals	0.03	0.04	0.05	-0.11	-1.76	0.06	0.16	0.03	0.02	-0.60	0.03	0.26	0.18	0.14	0.08
Mineral products, machinery and transport material	-0.12	0.02	-0.03	0.00	-0.34	-0.32	-0.04	-0.06	-0.07	-0.13	-0.57	-0.17	-0.19	-0.19	-0.22
Agri-food industry	0.49	0.06	0.26	0.08	0.32	1.32	0.47	0.47	0.51	0.36	2.35	1.11	1.17	1.16	1.15
Manufactures	0.06	0.03	0.05	-0.06	-1.09	0.16	0.14	0.05	0.05	-0.36	0.24	0.25	0.20	0.18	0.14
Rubber, plastics and others	0.02	0.06	0.07	-0.11	-2.09	0.02	0.20	0.04	0.03	-0.71	-0.03	0.30	0.20	0.16	0.07
Construction and engineering	-0.04	0.01	-0.01	-0.03	-0.56	-0.12	0.00	-0.04	-0.04	-0.22	-0.23	-0.03	-0.07	-0.08	-0.10
Hotels and restaurants	-0.13	-0.08	-0.12	0.05	1.55	-0.34	-0.29	-0.17	-0.17	0.44	-0.53	-0.53	-0.46	-0.42	-0.35
Rest of services	-0.08	0.00	-0.04	-0.01	-0.17	-0.22	-0.06	-0.07	-0.08	-0.10	-0.39	-0.16	-0.18	-0.18	-0.19
Standard deviation (%)	*1.77*	*0.89*	*0.79*	*1.11*	*5.54*	*4.61*	*2.39*	*2.59*	*2.54*	*4.28*	*8.02*	*4.62*	*4.72*	*4.77*	*4.73*

Source: Own work.

4.4. Appendix D: Supplements to Chapter 4

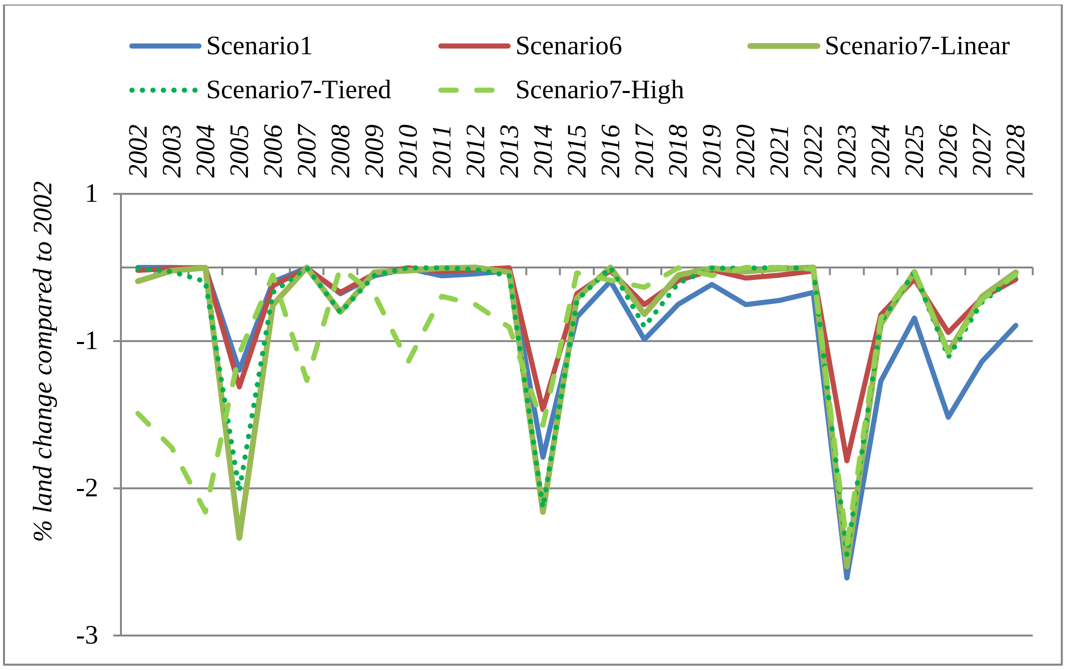
4.4.1. Supplementary figures

Figure D1. **Evolution of water supply in CGRAA**



Source: Own work based on the first period from Sánchez-Chóliz and Sarasa (2013 [164]).

Figure D2. **Evolution of total land area**



Source: Own work.

4.4.2. Supplementary tables

Table D1. **Total production results**

(*Variation in each year compared to benchmark scenario*)

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7 -Linear**	**Scenario 7 -Tiered**	**Scenario 7-High**
2002	0.00	0.12	0.06	0.11	1.00	0.24	0.19	0.14	-1.59
2003	0.00	0.15	0.10	0.14	1.02	0.29	0.29	0.17	-1.72
2004	0.03	0.20	0.17	0.20	1.04	0.37	0.37	0.17	-1.99
2005	-0.86	-0.67	-0.68	-0.67	1.06	-0.48	-0.83	-0.71	-0.59
2006	-0.39	-0.17	-0.17	-0.17	1.08	0.05	0.00	0.02	-0.63
2007	-0.17	0.08	0.09	0.08	1.11	0.31	0.30	0.27	-1.26
2008	-0.54	-0.27	-0.24	-0.27	1.13	0.00	-0.05	-0.07	-0.47
2009	-0.38	-0.09	-0.05	-0.09	1.15	0.19	0.19	0.17	-0.68
2010	-0.26	0.06	0.10	0.06	1.17	0.35	0.28	0.32	-1.06
2011	-0.43	-0.08	-0.03	-0.08	1.20	0.23	0.21	0.12	-0.64
2012	-0.43	-0.06	0.00	-0.06	1.22	0.27	0.23	0.14	-0.66
2013	-0.39	0.00	0.06	0.00	1.25	0.34	0.23	0.15	-0.76
2014	-1.33	-0.92	-0.82	-0.93	1.26	-0.55	-0.78	-0.79	-0.80
2015	-0.85	-0.41	-0.31	-0.42	1.29	-0.03	-0.05	-0.07	-0.31
2016	-0.62	-0.15	-0.06	-0.16	1.32	0.24	0.18	0.19	-0.37
2017	-1.01	-0.53	-0.41	-0.53	1.34	-0.11	-0.14	-0.19	-0.34
2018	-0.85	-0.34	-0.23	-0.35	1.37	0.08	0.07	0.05	-0.24
2019	-0.73	-0.19	-0.08	-0.20	1.40	0.24	0.16	0.21	-0.25
2020	-0.90	-0.35	-0.22	-0.35	1.43	0.10	0.08	0.01	-0.20
2021	-0.90	-0.33	-0.20	-0.33	1.46	0.13	0.10	0.03	-0.18
2022	-0.87	-0.27	-0.15	-0.28	1.49	0.20	0.12	0.05	-0.16
2023	-1.81	-1.21	-1.06	-1.22	1.50	-0.74	-0.97	-0.95	-1.14
2024	-1.34	-0.72	-0.56	-0.72	1.54	-0.21	-0.26	-0.26	-0.46
2025	-1.11	-0.46	-0.31	-0.46	1.58	0.05	0.03	0.01	-0.18
2026	-1.51	-0.84	-0.68	-0.84	1.60	-0.32	-0.39	-0.41	-0.60
2027	-1.36	-0.66	-0.50	-0.67	1.64	-0.13	-0.15	-0.18	-0.37
2028	-1.23	-0.51	-0.36	-0.52	1.67	0.02	0.00	-0.01	-0.20
Period 2002-2010	-0.29	-0.06	-0.07	-0.07	1.08	0.15	0.08	0.05	-1.11
Period 2011-2020	-0.74	-0.30	-0.21	-0.30	1.29	0.08	0.01	-0.02	-0.49
Period 2021-2028	-1.23	-0.60	-0.45	-0.60	1.54	-0.10	-0.16	-0.19	-0.39
Period 2002-2028	-0.75	-0.32	-0.24	-0.32	1.31	0.04	-0.02	-0.05	-0.66
Total change 2002-2028 Base 67.77%	*65.70*	*66.71*	*67.08*	*66.71*	*68.88*	*67.40*	*67.45*	*67.53*	*70.14*

Source: Own work.

Table D2. **Total consumption results**

(*Variation in each year compared to benchmark scenario*)

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7 -Linear**	**Scenario 7 -Tiered**	**Scenario 7-High**
2002	0.00	-0.95	-0.93	-0.94	-0.91	-0.90	-0.72	-1.39	-5.03
2003	0.00	-0.91	-0.91	-0.90	-0.87	-0.86	-0.77	-1.43	-5.36
2004	0.01	-0.86	-0.88	-0.86	-0.83	-0.82	-0.92	-1.59	-6.00
2005	-0.13	-1.00	-1.01	-0.99	-0.93	-0.90	-0.75	-0.75	-1.26
2006	-0.01	-0.83	-0.86	-0.83	-0.78	-0.77	-0.61	-0.71	-2.57
2007	0.01	-0.76	-0.81	-0.75	-0.71	-0.71	-0.88	-1.00	-4.30
2008	-0.03	-0.78	-0.83	-0.78	-0.72	-0.71	-0.56	-0.58	-2.01
2009	0.00	-0.71	-0.78	-0.70	-0.65	-0.65	-0.70	-0.64	-2.83
2010	0.01	-0.65	-0.74	-0.64	-0.59	-0.61	-1.02	-0.79	-3.85
2011	0.00	-0.64	-0.73	-0.63	-0.58	-0.58	-0.76	-1.10	-2.72
2012	0.00	-0.60	-0.70	-0.59	-0.54	-0.54	-0.85	-1.12	-2.81
2013	0.01	-0.55	-0.67	-0.55	-0.49	-0.51	-1.05	-1.24	-3.12
2014	-0.29	-0.84	-0.88	-0.84	-0.75	-0.67	-0.55	-0.57	-0.91
2015	-0.09	-0.60	-0.70	-0.60	-0.52	-0.49	-0.46	-0.46	-1.25
2016	-0.02	-0.49	-0.62	-0.49	-0.42	-0.42	-0.79	-0.68	-1.98
2017	-0.14	-0.58	-0.68	-0.58	-0.50	-0.45	-0.39	-0.36	-0.97
2018	-0.08	-0.49	-0.61	-0.48	-0.40	-0.38	-0.51	-0.37	-1.23
2019	-0.04	-0.41	-0.56	-0.40	-0.33	-0.32	-0.78	-0.47	-1.61
2020	-0.09	-0.43	-0.57	-0.42	-0.34	-0.32	-0.51	-0.80	-1.11
2021	-0.09	-0.39	-0.55	-0.39	-0.30	-0.28	-0.55	-0.79	-1.10
2022	-0.07	-0.34	-0.51	-0.34	-0.26	-0.24	-0.66	-0.87	-1.18
2023	-0.55	-0.81	-0.84	-0.80	-0.70	-0.53	-0.46	-0.47	-0.76
2024	-0.27	-0.49	-0.60	-0.48	-0.38	-0.29	-0.25	-0.28	-0.57
2025	-0.16	-0.34	-0.50	-0.33	-0.24	-0.18	-0.40	-0.40	-0.69
2026	-0.35	-0.51	-0.61	-0.50	-0.40	-0.27	-0.21	-0.22	-0.50
2027	-0.27	-0.39	-0.52	-0.38	-0.28	-0.18	-0.22	-0.19	-0.47
2028	-0.21	-0.29	-0.46	-0.29	-0.19	-0.11	-0.33	-0.22	-0.51
Period 2002-2010	-0.02	-0.83	-0.86	-0.82	-0.78	-0.77	-0.77	-0.99	-3.69
Period 2011-2020	-0.07	-0.58	-0.68	-0.57	-0.50	-0.48	-0.68	-0.71	-1.85
Period 2021-2028	-0.23	-0.44	-0.57	-0.44	-0.34	-0.27	-0.40	-0.47	-0.76
Period 2002-2028	-0.11	-0.62	-0.71	-0.61	-0.54	-0.51	-0.62	-0.72	-2.10
Total change 2002-2028 Base 67.77%	*67.42*	*68.53*	*68.57*	*68.88*	*69.00*	*69.10*	*68.43*	*69.75*	*75.76*

Source: Own work.

Table D3. **Total investment results**

(*Variation in each year compared to benchmark scenario*)

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7 -Linear**	**Scenario 7 -Tiered**	**Scenario 7-High**
2002	0.00	2.32	1.32	2.32	2.37	2.05	2.12	1.77	-0.83
2003	0.00	2.35	1.33	2.36	2.41	2.07	2.11	1.72	-1.12
2004	0.01	2.38	1.35	2.38	2.43	2.09	2.04	1.60	-1.67
2005	-0.11	2.40	1.33	2.40	2.49	2.15	1.93	2.00	1.97
2006	-0.01	2.48	1.40	2.48	2.55	2.20	2.23	2.20	1.07
2007	0.01	2.50	1.42	2.50	2.57	2.20	2.11	2.03	-0.32
2008	-0.03	2.54	1.44	2.54	2.62	2.26	2.28	2.27	1.48
2009	0.00	2.58	1.46	2.58	2.65	2.28	2.25	2.27	0.84
2010	0.01	2.60	1.47	2.61	2.67	2.28	2.05	2.18	0.01
2011	0.00	2.64	1.50	2.64	2.72	2.33	2.24	2.04	0.91
2012	0.00	2.67	1.52	2.67	2.75	2.36	2.20	2.03	0.83
2013	0.01	2.70	1.53	2.70	2.78	2.38	2.07	1.93	0.57
2014	-0.25	2.55	1.44	2.55	2.65	2.35	2.17	2.16	2.05
2015	-0.08	2.72	1.56	2.72	2.82	2.45	2.45	2.43	1.98
2016	-0.02	2.78	1.59	2.79	2.87	2.47	2.29	2.34	1.45
2017	-0.12	2.75	1.58	2.75	2.85	2.50	2.49	2.46	2.15
2018	-0.07	2.81	1.61	2.81	2.91	2.53	2.48	2.51	2.00
2019	-0.04	2.86	1.64	2.86	2.96	2.56	2.32	2.48	1.72
2020	-0.08	2.86	1.65	2.86	2.97	2.59	2.50	2.36	2.08
2021	-0.08	2.89	1.67	2.89	3.00	2.61	2.49	2.36	2.09
2022	-0.06	2.93	1.69	2.93	3.03	2.64	2.43	2.31	2.04
2023	-0.47	2.57	1.47	2.58	2.70	2.49	2.23	2.24	1.99
2024	-0.23	2.84	1.65	2.84	2.96	2.65	2.62	2.61	2.35
2025	-0.14	2.95	1.71	2.95	3.07	2.71	2.62	2.61	2.35
2026	-0.30	2.82	1.65	2.83	2.95	2.68	2.62	2.59	2.34
2027	-0.23	2.92	1.71	2.92	3.04	2.73	2.70	2.69	2.44
2028	-0.18	2.99	1.75	2.99	3.12	2.77	2.69	2.71	2.46
Period 2002-2010	-0.01	2.46	1.39	2.48	2.53	2.17	2.12	2.01	0.16
Period 2011-2020	-0.06	2.72	1.55	2.74	2.81	2.44	2.30	2.26	1.52
Period 2021-2028	-0.20	2.86	1.66	2.87	2.98	2.65	2.55	2.50	2.24
Period 2002-2028	-0.09	2.68	1.54	2.70	2.77	2.42	2.32	2.26	1.31
Total change 2002-2028 Base 67.77%	*67.47*	*68.87*	*68.48*	*68.87*	*68.98*	*68.96*	*68.71*	*69.33*	*73.34*

Source: Own work.

Table D4. **Total Irrigated agriculture production**

(*Variation in each year compared to benchmark scenario*)

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7 -Linear**	**Scenario 7 -Tiered**	**Scenario 7-High**
2002	0.00	0.03	0.22	0.00	7.80	8.24	-5.39	35.63	182.81
2003	0.20	0.30	1.39	0.27	8.10	9.55	3.89	41.21	195.76
2004	1.38	1.58	3.50	1.54	9.48	11.87	17.89	52.63	219.97
2005	-26.22	-26.11	-23.48	-26.11	-20.61	-17.58	-44.83	-39.60	-5.04
2006	-12.35	-12.11	-8.59	-12.12	-5.30	-1.23	-14.04	-6.71	78.30
2007	-5.19	-4.83	-0.60	-4.85	2.60	7.53	17.52	23.41	156.58
2008	-16.68	-16.35	-11.45	-16.36	-9.91	-4.30	-16.07	-16.46	51.65
2009	-11.90	-11.47	-5.90	-11.48	-4.59	1.82	4.58	-0.58	94.47
2010	-7.97	-7.42	-1.25	-7.44	-0.19	6.93	30.53	16.94	140.65
2011	-13.10	-12.55	-5.78	-12.56	-5.75	2.01	12.78	30.43	91.21
2012	-12.94	-12.33	-5.01	-12.34	-5.50	2.89	20.57	33.69	96.52
2013	-11.83	-11.14	-3.32	-11.16	-4.20	4.79	34.57	43.23	111.78
2014	-37.81	-37.42	-29.82	-37.42	-33.00	-24.40	-44.40	-43.95	-31.08
2015	-25.04	-24.44	-15.76	-24.44	-18.73	-8.83	-12.29	-13.93	16.18
2016	-18.29	-17.52	-8.28	-17.53	-11.14	-0.56	20.10	13.04	62.03
2017	-29.19	-28.56	-19.13	-28.56	-23.25	-12.51	-18.36	-23.90	-0.42
2018	-24.77	-24.01	-14.02	-24.01	-18.24	-6.83	0.55	-10.08	22.47
2019	-21.07	-20.19	-9.77	-20.20	-14.05	-2.10	23.19	4.90	47.97
2020	-25.99	-25.16	-14.44	-25.16	-19.49	-7.24	3.88	18.24	18.81
2021	-25.89	-25.01	-13.95	-25.02	-19.33	-6.66	8.66	20.23	20.82
2022	-24.89	-23.94	-12.53	-23.95	-18.15	-5.05	18.42	27.57	28.21
2023	-48.58	-48.09	-38.08	-48.09	-44.70	-33.40	-50.69	-49.53	-49.50
2024	-37.26	-36.50	-25.03	-36.50	-31.96	-18.88	-24.09	-23.22	-23.03
2025	-31.11	-30.17	-18.04	-30.18	-24.99	-11.08	0.69	-0.42	-0.03
2026	-41.11	-40.38	-28.67	-40.38	-36.23	-22.89	-31.04	-32.68	-32.56
2027	-37.18	-36.32	-24.00	-36.32	-31.75	-17.66	-17.07	-21.14	-20.93
2028	-33.86	-32.88	-20.10	-32.89	-27.96	-13.29	-1.51	-8.96	-8.66
Period 2002-2010	-8.75	-8.49	-5.13	-8.51	-1.40	2.54	-0.66	11.83	123.90
Period 2011-2020	-21.56	-20.90	-12.32	-20.91	-14.87	-5.06	4.08	3.71	46.30
Period 2021-2028	-33.99	-33.16	-21.65	-33.17	-28.29	-15.13	-10.31	-7.77	-7.43
Period 2002-2028	-21.43	-20.85	-13.03	-20.86	-14.85	-5.88	-2.29	2.59	54.26
Total change 2002-2028 Base 67.77%	*10.95*	*12.57*	*33.75*	*12.60*	*12.12*	*34.40*	*74.64*	*12.62*	*-45.81*

Source: Own work.

Table D5. **Total rest of farming production**

(*Variation in each year compared to benchmark scenario*)

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7 -Linear**	**Scenario 7 -Tiered**	**Scenario 7-High**
2002	0.00	0.10	-0.63	-0.08	1.00	0.44	0.60	-2.64	-30.58
2003	-0.13	0.09	-0.37	-0.10	0.99	0.72	0.98	-2.82	-32.21
2004	0.09	0.42	0.20	0.23	1.30	1.30	0.88	-3.62	-35.48
2005	-12.92	-12.58	-11.88	-12.76	-11.35	-10.54	-13.76	-12.20	-12.00
2006	-5.92	-5.41	-4.75	-5.61	-4.34	-3.47	-3.32	-3.32	-16.13
2007	-3.03	-2.38	-1.73	-2.59	-1.41	-0.48	-1.26	-1.93	-26.33
2008	-8.40	-7.71	-6.34	-7.91	-6.59	-4.98	-4.85	-4.91	-13.31
2009	-6.33	-5.52	-4.12	-5.73	-4.46	-2.77	-2.95	-2.72	-17.86
2010	-4.81	-3.87	-2.49	-4.09	-2.87	-1.14	-3.46	-1.97	-23.92
2011	-7.30	-6.30	-4.43	-6.52	-5.23	-3.02	-3.87	-6.07	-17.44
2012	-7.45	-6.35	-4.30	-6.57	-5.28	-2.86	-4.46	-6.24	-18.07
2013	-7.15	-5.95	-3.81	-6.18	-4.90	-2.36	-5.52	-6.87	-20.02
2014	-21.98	-20.96	-17.03	-21.17	-19.66	-15.44	-17.10	-17.04	-16.17
2015	-14.27	-13.02	-9.60	-13.25	-11.82	-8.02	-7.94	-7.97	-11.43
2016	-10.90	-9.49	-6.39	-9.73	-8.36	-4.82	-6.78	-6.02	-14.25
2017	-17.09	-15.72	-11.65	-15.95	-14.49	-10.01	-9.91	-10.07	-11.81
2018	-14.75	-13.25	-9.34	-13.50	-12.06	-7.69	-8.24	-7.67	-11.67
2019	-12.98	-11.35	-7.61	-11.61	-10.21	-5.96	-8.49	-6.53	-13.15
2020	-15.87	-14.23	-9.93	-14.48	-13.03	-8.23	-9.11	-10.87	-11.73
2021	-16.03	-14.31	-9.89	-14.57	-13.12	-8.17	-9.49	-10.99	-11.85
2022	-15.69	-13.88	-9.44	-14.15	-12.71	-7.69	-9.99	-11.32	-12.19
2023	-31.74	-30.31	-23.92	-30.55	-29.01	-22.18	-23.84	-23.58	-24.16
2024	-23.64	-21.91	-16.13	-22.17	-20.64	-14.32	-14.28	-14.33	-15.02
2025	-19.95	-18.04	-12.66	-18.30	-16.82	-10.83	-11.79	-11.73	-12.49
2026	-26.70	-24.93	-18.58	-25.19	-23.66	-16.74	-16.78	-16.91	-17.53
2027	-24.22	-22.30	-16.16	-22.57	-21.05	-14.29	-14.39	-14.31	-14.97
2028	-22.29	-20.25	-14.31	-20.52	-19.02	-12.41	-13.36	-12.78	-13.48
Period 2002-2010	-4.61	-4.10	-3.57	-4.29	-3.08	-3.47	-3.02	-4.01	-23.09
Period 2011-2020	-12.65	-11.38	-8.24	-11.61	-10.22	-11.07	-8.03	-8.27	-14.89
Period 2021-2028	-21.79	-20.02	-14.56	-20.28	-18.78	-19.93	-13.67	-14.09	-14.83
Period 2002-2028	-13.02	-11.83	-8.79	-12.06	-10.70	-11.49	-8.24	-8.79	-17.60
Total change 2002-2028 Base 67.77%	*30.37*	*33.67*	*44.67*	*33.45*	*34.51*	*46.31*	*44.48*	*50.30*	*109.10*

Source: Own work.

Table D6. **Total industrial production**

(*Variation in each year compared to benchmark scenario*)

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7 -Linear**	**Scenario 7 -Tiered**	**Scenario 7-High**
2002	0.00	0.51	0.45	0.52	0.12	0.17	0.82	-1.21	-9.41
2003	0.00	0.53	0.43	0.54	0.14	0.15	0.42	-1.46	-10.17
2004	-0.03	0.51	0.36	0.52	0.11	0.08	-0.21	-2.02	-11.59
2005	1.20	1.79	1.57	1.80	1.48	1.40	2.62	2.38	0.71
2006	0.57	1.17	0.92	1.18	0.81	0.70	1.30	0.95	-3.55
2007	0.28	0.88	0.61	0.90	0.51	0.36	-0.14	-0.45	-7.88
2008	0.79	1.43	1.09	1.44	1.09	0.89	1.44	1.45	-2.10
2009	0.59	1.24	0.88	1.25	0.89	0.66	0.52	0.76	-4.37
2010	0.43	1.10	0.70	1.11	0.73	0.47	-0.72	-0.04	-6.93
2011	0.67	1.36	0.92	1.37	1.00	0.71	0.18	-0.73	-4.17
2012	0.67	1.38	0.91	1.39	1.03	0.71	-0.18	-0.87	-4.44
2013	0.63	1.36	0.86	1.37	1.00	0.66	-0.86	-1.33	-5.27
2014	1.89	2.66	2.09	2.68	2.40	2.00	2.88	2.85	2.12
2015	1.26	2.04	1.45	2.05	1.73	1.31	1.46	1.53	-0.13
2016	0.96	1.74	1.15	1.76	1.41	0.98	-0.07	0.28	-2.48
2017	1.48	2.30	1.65	2.32	2.01	1.54	1.80	2.04	0.75
2018	1.28	2.11	1.44	2.13	1.81	1.31	0.94	1.44	-0.36
2019	1.12	1.96	1.28	1.98	1.65	1.13	-0.15	0.77	-1.65
2020	1.36	2.23	1.51	2.25	1.93	1.39	0.83	0.10	-0.12
2021	1.37	2.26	1.51	2.27	1.96	1.40	0.63	0.03	-0.19
2022	1.34	2.24	1.47	2.25	1.94	1.35	0.17	-0.32	-0.53
2023	2.60	3.55	2.72	3.56	3.33	2.72	3.46	3.40	3.23
2024	1.97	2.93	2.09	2.94	2.67	2.04	2.26	2.21	2.03
2025	1.67	2.63	1.79	2.65	2.36	1.71	1.12	1.16	0.97
2026	2.20	3.20	2.31	3.21	2.96	2.29	2.64	2.70	2.53
2027	2.00	3.01	2.11	3.02	2.76	2.07	2.02	2.20	2.02
2028	1.84	2.86	1.95	2.88	2.60	1.90	1.31	1.66	1.47
Period 2002-2010	0.42	1.02	0.78	1.03	0.65	0.54	0.67	0.04	-6.14
Period 2011-2020	1.11	1.88	1.31	1.89	1.56	1.15	0.67	0.66	-1.74
Period 2021-2028	1.82	2.77	1.94	2.78	2.50	1.88	1.61	1.46	1.27
Period 2002-2028	1.12	1.89	1.34	1.90	1.57	1.19	0.98	0.72	-2.20
Total change 2002-2028 Base 67.77%	*70.86*	*71.69*	*70.27*	*71.70*	*71.92*	*70.66*	*68.59*	*72.65*	*87.93*

Source: Own work.

Table D7. **Total services production**

(*Variation in each year compared to benchmark scenario*)

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7 -Linear**	**Scenario 7 -Tiered**	**Scenario 7-High**
2002	0.00	-0.37	-0.38	-0.37	-0.32	-0.35	-0.19	-0.73	-3.31
2003	0.00	-0.35	-0.36	-0.34	-0.29	-0.33	-0.26	-0.77	-3.54
2004	0.00	-0.32	-0.35	-0.32	-0.27	-0.31	-0.39	-0.90	-4.00
2005	0.05	-0.26	-0.31	-0.26	-0.19	-0.24	-0.02	-0.05	-0.49
2006	0.04	-0.25	-0.30	-0.25	-0.19	-0.24	-0.10	-0.19	-1.54
2007	0.02	-0.24	-0.30	-0.24	-0.18	-0.23	-0.37	-0.46	-2.80
2008	0.05	-0.20	-0.27	-0.19	-0.13	-0.19	-0.06	-0.07	-1.13
2009	0.04	-0.18	-0.26	-0.18	-0.11	-0.18	-0.21	-0.16	-1.74
2010	0.04	-0.16	-0.25	-0.16	-0.09	-0.17	-0.49	-0.31	-2.49
2011	0.05	-0.13	-0.23	-0.13	-0.06	-0.14	-0.28	-0.54	-1.67
2012	0.05	-0.10	-0.21	-0.10	-0.03	-0.12	-0.35	-0.55	-1.74
2013	0.06	-0.08	-0.20	-0.08	-0.01	-0.10	-0.51	-0.66	-1.97
2014	0.07	-0.06	-0.17	-0.06	0.03	-0.04	0.12	0.11	-0.16
2015	0.07	-0.03	-0.16	-0.02	0.05	-0.03	0.00	0.00	-0.56
2016	0.07	-0.01	-0.15	0.00	0.07	-0.02	-0.31	-0.22	-1.14
2017	0.08	0.02	-0.13	0.02	0.10	0.02	0.07	0.11	-0.34
2018	0.08	0.04	-0.12	0.04	0.13	0.03	-0.07	0.04	-0.57
2019	0.08	0.06	-0.11	0.07	0.14	0.04	-0.31	-0.07	-0.88
2020	0.08	0.09	-0.09	0.09	0.17	0.07	-0.08	-0.29	-0.48
2021	0.09	0.11	-0.07	0.11	0.20	0.09	-0.12	-0.29	-0.48
2022	0.09	0.13	-0.06	0.13	0.22	0.11	-0.22	-0.36	-0.55
2023	0.05	0.11	-0.06	0.11	0.21	0.14	0.26	0.24	0.07
2024	0.08	0.16	-0.03	0.16	0.26	0.16	0.20	0.18	0.00
2025	0.09	0.19	-0.02	0.19	0.28	0.18	0.01	0.01	-0.17
2026	0.07	0.19	-0.01	0.19	0.29	0.20	0.27	0.27	0.10
2027	0.08	0.22	0.01	0.22	0.32	0.22	0.19	0.23	0.05
2028	0.09	0.24	0.02	0.25	0.34	0.24	0.07	0.15	-0.02
Period 2002-2010	0.03	-0.26	-0.31	-0.26	-0.20	-0.06	-0.23	-0.40	-2.34
Period 2011-2020	0.07	-0.03	-0.16	-0.03	0.05	0.08	-0.18	-0.20	-1.00
Period 2021-2028	0.08	0.16	-0.03	0.16	0.25	0.18	0.06	0.01	-0.17
Period 2002-2028	0.06	-0.04	-0.17	-0.04	0.04	0.07	-0.12	-0.20	-1.17
Total change 2002-2028 Base 67.77%	*67.92*	*68.80*	*68.44*	*68.81*	*68.88*	*68.76*	*68.22*	*69.26*	*73.47*

Source: Own work.

Table D8. **Total land**

(*Variation in each year compared to land in 2002*)

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7 -Linear**	**Scenario 7 -Tiered**	**Scenario 7-High**
2002	0.00	1.60	0.00	-0.03	0.00	-0.02	-0.09	-0.01	-0.99
2003	0.00	1.62	0.00	-0.02	0.00	-0.01	-0.02	-0.03	-1.22
2004	-0.01	1.65	-0.02	-0.01	-0.01	0.00	0.00	-0.10	-1.66
2005	-0.70	0.61	-0.55	-1.02	-0.73	-0.81	-1.84	-1.52	-0.58
2006	-0.10	1.43	-0.04	-0.24	-0.11	-0.13	-0.26	-0.17	-0.05
2007	0.00	1.63	0.00	-0.05	-0.01	-0.01	0.00	0.00	-0.77
2008	-0.18	1.32	-0.07	-0.36	-0.19	-0.17	-0.30	-0.31	0.00
2009	-0.06	1.53	0.00	-0.17	-0.07	-0.04	-0.03	-0.05	-0.18
2010	-0.01	1.64	-0.01	-0.07	-0.01	0.00	-0.02	0.00	-0.65
2011	-0.06	1.54	0.00	-0.17	-0.07	-0.03	-0.01	0.00	-0.20
2012	-0.04	1.57	0.00	-0.15	-0.06	-0.02	0.00	-0.01	-0.25
2013	-0.02	1.62	-0.01	-0.11	-0.03	0.00	-0.03	-0.06	-0.41
2014	-1.29	-0.05	-0.68	-1.74	-1.40	-0.97	-1.66	-1.63	-1.07
2015	-0.34	1.15	-0.07	-0.58	-0.38	-0.18	-0.21	-0.23	-0.04
2016	-0.09	1.51	0.00	-0.24	-0.12	-0.02	0.00	0.00	-0.09
2017	-0.49	0.95	-0.12	-0.78	-0.56	-0.25	-0.32	-0.40	-0.14
2018	-0.25	1.28	-0.02	-0.47	-0.30	-0.09	-0.05	-0.11	0.00
2019	-0.12	1.49	0.00	-0.27	-0.15	-0.02	0.00	0.00	-0.05
2020	-0.25	1.28	-0.02	-0.47	-0.30	-0.07	-0.03	0.00	0.00
2021	-0.23	1.33	-0.01	-0.43	-0.27	-0.05	-0.01	0.00	0.00
2022	-0.17	1.41	0.00	-0.35	-0.21	-0.03	0.00	-0.01	-0.01
2023	-2.11	-0.98	-0.97	-2.70	-2.31	-1.31	-2.03	-1.95	-1.89
2024	-0.77	0.61	-0.17	-1.14	-0.89	-0.32	-0.39	-0.37	-0.35
2025	-0.34	1.16	-0.02	-0.60	-0.42	-0.08	-0.03	-0.03	-0.03
2026	-1.02	0.30	-0.26	-1.44	-1.16	-0.44	-0.58	-0.61	-0.58
2027	-0.64	0.77	-0.09	-0.98	-0.75	-0.21	-0.20	-0.24	-0.22
2028	-0.39	1.08	-0.02	-0.67	-0.48	-0.08	-0.03	-0.06	-0.05
Period 2002-2010	-0.12	1.45	-0.08	-0.22	-0.12	-0.12	-0.29	-0.24	-0.68
Period 2011-2020	-0.30	1.23	-0.10	-0.50	-0.34	-0.32	-0.25	-0.27	-0.25
Period 2021-2028	-0.66	0.77	-0.17	-0.98	-0.75	-0.70	-0.37	-0.36	-0.35
Period 2002-2028	-0.36	1.13	-0.12	-0.56	-0.41	-0.38	-0.30	-0.29	-0.42
Total change 2002-2028 Base 67.77%	*-0.39*	*-0.51*	*-0.02*	*-0.64*	*-0.48*	*-0.06*	*0.06*	*-0.05*	*0.95*

Source: Own work.

Table D9. **Irrigated land**

(*Variation in each year compared to to land in 2002*)

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7 -Linear**	**Scenario 7 -Tiered**	**Scenario 7-High**
2002	0.00	3.59	0.01	1.99	0.02	2.07	1.48	2.81	4.92
2003	0.08	3.66	0.17	2.06	0.09	2.23	2.03	3.06	5.08
2004	0.24	3.84	0.41	2.23	0.25	2.48	2.66	3.43	5.32
2005	-3.33	-0.13	-2.87	-1.64	-3.41	-1.11	-3.53	-2.83	-0.46
2006	-1.10	2.31	-0.69	0.74	-1.14	1.26	0.66	1.03	3.18
2007	-0.21	3.29	0.19	1.69	-0.24	2.21	2.52	2.67	4.65
2008	-1.52	1.81	-0.90	0.25	-1.59	1.01	0.44	0.43	2.55
2009	-0.82	2.57	-0.21	1.00	-0.88	1.75	1.85	1.67	3.68
2010	-0.30	3.14	0.30	1.55	-0.35	2.30	2.90	2.59	4.48
2011	-0.81	2.54	-0.08	0.98	-0.90	1.88	2.21	2.64	3.69
2012	-0.72	2.63	0.06	1.07	-0.81	2.02	2.51	2.80	3.83
2013	-0.51	2.84	0.28	1.28	-0.60	2.25	2.97	3.13	4.12
2014	-4.84	-1.97	-3.26	-3.42	-5.09	-1.61	-3.24	-3.18	-1.88
2015	-2.17	0.94	-0.95	-0.56	-2.34	0.89	0.75	0.69	1.75
2016	-1.08	2.15	-0.02	0.63	-1.21	1.90	2.46	2.30	3.27
2017	-2.70	0.32	-1.24	-1.15	-2.90	0.56	0.30	0.00	1.09
2018	-1.84	1.25	-0.51	-0.23	-2.02	1.34	1.60	1.23	2.22
2019	-1.20	1.94	0.02	0.46	-1.36	1.92	2.57	2.14	3.07
2020	-1.84	1.19	-0.42	-0.25	-2.04	1.43	1.79	2.14	2.22
2021	-1.73	1.30	-0.29	-0.14	-1.93	1.57	2.02	2.29	2.36
2022	-1.48	1.55	-0.06	0.13	-1.67	1.81	2.42	2.60	2.67
2023	-6.64	-4.15	-4.07	-5.46	-7.06	-2.53	-4.11	-3.95	-3.81
2024	-3.53	-0.79	-1.50	-2.13	-3.84	0.23	-0.01	0.04	0.14
2025	-2.20	0.66	-0.46	-0.69	-2.45	1.35	1.72	1.70	1.77
2026	-4.18	-1.55	-1.89	-2.85	-4.53	-0.21	-0.63	-0.73	-0.63
2027	-3.16	-0.46	-1.07	-1.76	-3.47	0.67	0.70	0.54	0.62
2028	-2.37	0.38	-0.47	-0.91	-2.65	1.32	1.69	1.48	1.55
Period 2002-2010	-0.77	2.67	-0.40	1.10	-0.81	-0.77	1.22	1.65	3.71
Period 2011-2020	-1.76	1.40	-0.63	-0.10	-1.91	-1.83	1.35	1.31	2.35
Period 2021-2028	-3.01	-0.21	-1.14	-1.56	-3.29	-3.14	0.62	0.68	0.77
Period 2002-2028	-1.85	1.29	-0.72	-0.19	-2.00	-1.91	1.06	1.21	2.28
Total change 2002-2028 Base 67.77%	*-2.37*	*-3.10*	*-0.48*	*-2.85*	*-2.68*	*-0.73*	*0.21*	*-1.30*	*-3.21*

Source: Own work.

Table D10. **Non-irrigated land**

(*Variation in each year compared to to land in 2002*)

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7 -Linear**	**Scenario 7 -Tiered**	**Scenario 7-High**
2002	0.00	-2.21	-0.02	-3.91	-0.04	-4.04	-3.12	-5.43	-3.12
2003	-0.15	-2.29	-0.34	-4.02	-0.18	-4.31	-3.96	-5.96	-3.96
2004	-0.48	-2.55	-0.83	-4.30	-0.50	-4.76	-5.12	-6.87	-5.12
2005	4.35	2.02	3.92	0.18	4.42	-0.25	1.41	1.00	1.41
2006	1.82	-0.26	1.20	-2.10	1.88	-2.78	-2.01	-2.48	-2.01
2007	0.39	-1.56	-0.38	-3.41	0.44	-4.27	-4.83	-5.14	-4.83
2008	2.40	0.39	1.53	-1.52	2.49	-2.43	-1.74	-1.72	-1.74
2009	1.41	-0.48	0.40	-2.41	1.50	-3.49	-3.64	-3.36	-3.64
2010	0.55	-1.23	-0.59	-3.19	0.65	-4.42	-5.64	-4.98	-5.64
2011	1.40	-0.37	0.15	-2.37	1.52	-3.69	-4.26	-5.07	-4.26
2012	1.25	-0.45	-0.11	-2.49	1.39	-3.92	-4.83	-5.42	-4.83
2013	0.92	-0.71	-0.55	-2.78	1.06	-4.33	-5.80	-6.18	-5.80
2014	5.53	3.64	4.29	1.48	5.70	0.26	1.38	1.34	1.38
2015	3.19	1.54	1.60	-0.63	3.37	-2.24	-2.06	-1.98	-2.06
2016	1.79	0.28	0.04	-1.90	1.98	-3.71	-4.73	-4.42	-4.73
2017	3.75	2.17	2.02	-0.08	3.95	-1.81	-1.50	-1.18	-1.50
2018	2.80	1.35	0.92	-0.93	3.02	-2.84	-3.22	-2.68	-3.22
2019	1.96	0.61	-0.05	-1.68	2.18	-3.75	-4.95	-4.13	-4.95
2020	2.80	1.46	0.75	-0.89	3.04	-2.97	-3.52	-4.13	-3.52
2021	2.67	1.38	0.53	-1.00	2.91	-3.17	-3.91	-4.39	-3.91
2022	2.34	1.13	0.11	-1.28	2.59	-3.55	-4.65	-5.02	-4.65
2023	6.59	5.12	4.96	2.60	6.80	1.03	1.97	1.88	1.97
2024	4.53	3.28	2.37	0.76	4.78	-1.38	-1.12	-1.17	-1.12
2025	3.22	2.11	0.83	-0.42	3.49	-2.83	-3.40	-3.36	-3.40
2026	5.05	3.87	2.86	1.27	5.31	-0.89	-0.47	-0.37	-0.47
2027	4.19	3.12	1.79	0.51	4.47	-1.89	-1.93	-1.72	-1.93
2028	3.41	2.44	0.85	-0.19	3.70	-2.77	-3.34	-3.01	-3.34
Period 2002-2010	1.14	-0.91	0.54	-2.74	1.18	1.13	-3.18	-3.88	-3.18
Period 2011-2020	2.51	0.89	0.92	-1.26	2.69	2.58	-3.33	-3.30	-3.33
Period 2021-2028	3.87	2.66	1.67	0.15	4.12	3.99	-2.27	-2.37	-2.27
Period 2002-2028	2.51	0.88	1.05	-1.28	2.66	2.57	-2.93	-3.18	-2.93
Total change 2002-2028 Base 67.77%	*3.41*	*4.76*	*0.87*	*3.86*	*3.75*	*1.32*	*-0.23*	*2.56*	*-0.23*

Source: Own work.

Table D11. **Cereals and legumes production**

(*Variation in each year compared to benchmark scenario*)

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7 -Linear**	**Scenario 7 -Tiered**	**Scenario 7-High**
2002	0.00	0.45	0.00	0.00	0.00	2.70	-3.10	4.16	-35.43
2003	0.17	2.14	2.26	0.88	5.31	4.43	-1.59	5.32	-35.24
2004	1.95	5.31	5.47	2.74	7.13	7.66	-0.10	6.66	-36.05
2005	-42.38	-38.20	-38.09	-42.27	-38.93	-36.73	-32.70	-32.31	-39.62
2006	-20.77	-14.79	-14.57	-20.38	-16.34	-12.80	-11.82	-10.66	-30.31
2007	-9.25	-2.02	-1.79	-8.62	-4.40	0.25	-2.65	-1.53	-31.45
2008	-27.87	-19.75	-19.49	-27.56	-23.77	-17.87	-15.74	-15.80	-30.21
2009	-20.37	-11.01	-10.74	-19.92	-15.95	-8.92	-8.50	-9.42	-28.91
2010	-14.16	-3.79	-3.53	-13.56	-9.51	-1.53	-3.32	-5.94	-29.74
2011	-22.49	-11.25	-10.96	-22.04	-18.18	-9.15	-14.79	-11.17	-28.24
2012	-22.36	-10.25	-9.96	-21.88	-18.05	-8.12	-14.19	-11.48	-28.02
2013	-20.73	-7.80	-7.51	-20.19	-16.35	-5.59	-13.13	-11.32	-28.09
2014	-59.02	-48.38	-48.14	-59.05	-56.46	-47.17	-43.14	-43.07	-45.59
2015	-41.18	-27.69	-27.35	-40.98	-37.75	-25.97	-24.98	-25.29	-31.41
2016	-31.11	-16.28	-15.96	-30.72	-27.20	-14.26	-16.89	-18.33	-27.49
2017	-47.31	-33.13	-32.79	-47.18	-44.19	-31.55	-29.33	-30.37	-34.18
2018	-40.98	-25.55	-25.21	-40.74	-37.56	-23.77	-23.15	-25.26	-30.03
2019	-35.61	-19.25	-18.92	-35.25	-31.94	-17.29	-18.62	-22.36	-27.78
2020	-42.90	-26.57	-26.22	-42.67	-39.59	-24.81	-30.18	-27.07	-30.33
2021	-42.84	-26.02	-25.67	-42.59	-39.53	-24.23	-29.87	-27.36	-30.02
2022	-41.48	-24.09	-23.75	-41.18	-38.11	-22.25	-29.02	-27.04	-29.19
2023	-72.39	-60.16	-59.94	-72.50	-70.52	-59.25	-55.52	-55.30	-55.46
2024	-58.59	-42.70	-42.35	-58.55	-56.06	-41.37	-40.42	-40.24	-40.43
2025	-50.42	-32.83	-32.46	-50.25	-47.51	-31.22	-33.45	-33.69	-33.53
2026	-63.55	-48.00	-47.66	-63.56	-61.27	-46.81	-44.65	-45.00	-44.63
2027	-58.60	-41.66	-41.30	-58.53	-56.08	-40.30	-39.56	-40.43	-39.57
2028	-54.30	-36.32	-35.95	-54.15	-51.59	-34.80	-35.70	-37.31	-35.75
Period 2002-2010	-14.74	-10.26	-8.94	-14.30	-10.72	-10.72	-8.84	-6.61	-33.00
Period 2011-2020	-35.64	-22.62	-21.87	-35.34	-31.97	-31.97	-22.02	-22.07	-31.20
Period 2021-2028	-53.90	-39.69	-37.26	-53.77	-51.14	-51.14	-37.60	-37.05	-37.66
Period 2002-2028	-34.76	-22.95	-22.69	-34.47	-31.28	-31.28	-22.82	-21.91	-33.95
Total change 2002-2028 Base 67.77%	*-23.34*	*6.37*	*6.37*	*-23.99*	*-23.64*	*6.51*	*11.32*	*0.98*	*66.93*

Source: Own work.

Table D12. **Industrial crops production**

(*Variation in each year compared to benchmark scenario*)

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7 -Linear**	**Scenario 7 -Tiered**	**Scenario 7-High**
2002	0.00	0.33	0.00	0.00	0.00	4.27	1.22	3.38	-25.28
2003	0.32	2.23	2.42	0.60	10.43	6.34	5.52	5.80	-25.14
2004	2.31	5.85	6.09	2.65	12.89	10.28	10.85	9.05	-25.94
2005	-33.07	-30.49	-30.25	-33.02	-28.40	-28.51	-35.12	-32.60	-28.83
2006	-17.80	-13.10	-12.89	-17.71	-11.18	-10.15	-11.83	-10.62	-19.75
2007	-8.10	-1.30	-1.03	-7.88	0.25	2.54	2.99	2.88	-20.97
2008	-23.03	-16.94	-16.72	-22.95	-17.16	-14.22	-15.55	-15.63	-19.76
2009	-17.27	-9.48	-9.23	-17.14	-10.55	-6.26	-6.12	-6.45	-18.31
2010	-12.07	-2.51	-2.22	-11.86	-4.45	1.25	1.05	1.64	-18.99
2011	-18.78	-9.41	-9.15	-18.64	-12.28	-6.17	-6.00	-7.26	-17.56
2012	-18.60	-8.34	-8.08	-18.44	-12.07	-5.02	-5.12	-6.32	-17.23
2013	-17.21	-5.86	-5.59	-17.02	-10.45	-2.34	-3.36	-4.44	-17.12
2014	-43.56	-36.77	-36.54	-43.41	-39.72	-34.98	-38.38	-38.23	-35.63
2015	-32.02	-22.41	-22.23	-31.90	-27.19	-19.95	-20.14	-20.28	-21.38
2016	-24.93	-13.10	-12.89	-24.79	-19.27	-10.07	-10.59	-10.14	-16.66
2017	-36.02	-26.25	-26.08	-35.89	-31.56	-23.97	-24.32	-25.03	-24.40
2018	-31.77	-20.47	-20.32	-31.65	-26.90	-17.88	-17.85	-18.07	-19.75
2019	-27.99	-15.19	-15.03	-27.85	-22.70	-12.27	-13.31	-12.18	-16.86
2020	-32.99	-21.03	-20.91	-32.86	-28.24	-18.46	-18.57	-19.69	-19.98
2021	-32.91	-20.47	-20.36	-32.77	-28.14	-17.86	-18.19	-19.24	-19.53
2022	-31.94	-18.79	-18.68	-31.79	-27.07	-16.06	-17.04	-18.07	-18.38
2023	-52.25	-44.04	-43.88	-52.05	-48.96	-42.45	-45.28	-44.91	-45.06
2024	-43.19	-32.46	-32.39	-43.04	-39.29	-30.41	-30.70	-30.65	-30.83
2025	-37.85	-25.27	-25.24	-37.72	-33.53	-22.88	-23.08	-23.04	-23.27
2026	-46.39	-35.93	-35.89	-46.23	-42.71	-34.01	-34.60	-34.83	-34.99
2027	-43.16	-31.51	-31.51	-43.01	-39.26	-29.40	-29.41	-29.58	-29.76
2028	-40.33	-27.56	-27.58	-40.20	-36.21	-25.25	-25.47	-25.25	-25.46
Period 2002-2010	-12.08	-8.22	-7.09	-11.93	-5.35	-5.35	-5.22	-4.73	-22.55
Period 2011-2020	-27.87	-17.88	-17.32	-27.73	-22.46	-22.46	-15.45	-15.77	-20.73
Period 2021-2028	-40.11	-30.05	-28.49	-39.96	-35.94	-35.94	-26.93	-27.25	-27.47
Period 2002-2028	-26.69	-17.79	-17.64	-26.54	-21.25	-21.25	-15.87	-15.92	-23.59
Total change 2002-2028 Base 67.77%	*0.11*	*21.14*	*21.14*	*1.06*	*-0.09*	*20.27*	*23.52*	*21.30*	*67.36*

Source: Own work.

Table D13. **Fruit and vegetables production**

(*Variation in each year compared to benchmark scenario*)

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7 -Linear**	**Scenario 7 -Tiered**	**Scenario 7-High**
2002	0.00	0.20	0.00	0.01	0.00	13.02	-12.02	68.23	381.24
2003	0.17	1.04	0.99	0.30	43.20	14.03	3.30	77.48	406.65
2004	0.98	2.43	2.34	1.22	44.56	15.67	27.30	97.76	455.06
2005	-21.62	-18.87	-18.62	-21.39	8.91	-9.07	-58.18	-49.70	16.09
2006	-9.02	-5.83	-5.89	-8.63	28.90	6.23	-18.04	-4.32	171.25
2007	-3.39	0.08	-0.15	-2.83	37.90	13.13	32.71	44.51	326.22
2008	-12.67	-8.00	-8.07	-12.12	23.25	3.77	-18.65	-19.36	118.98
2009	-8.55	-3.54	-3.77	-7.86	29.86	9.02	14.42	4.40	201.87
2010	-5.35	-0.11	-0.47	-4.51	35.02	13.07	60.15	32.73	293.31
2011	-9.47	-3.30	-3.62	-8.61	28.54	9.39	30.67	66.64	194.88
2012	-9.30	-2.65	-3.02	-8.34	28.88	10.21	45.41	72.33	205.07
2013	-8.33	-1.31	-1.76	-7.26	30.51	11.82	71.74	89.70	235.04
2014	-33.36	-24.82	-24.67	-32.73	-9.21	-15.81	-52.93	-52.15	-28.57
2015	-20.25	-11.28	-11.52	-19.28	11.54	0.18	-6.53	-9.68	50.92
2016	-13.84	-4.87	-5.37	-12.64	21.84	7.78	49.18	34.83	136.90
2017	-24.32	-14.24	-14.46	-23.32	5.14	-3.25	-14.60	-25.06	21.11
2018	-19.89	-9.56	-9.98	-18.71	12.24	2.33	16.96	-3.97	61.89
2019	-16.32	-5.86	-6.46	-14.95	18.02	6.75	57.69	20.59	109.53
2020	-21.04	-9.80	-10.29	-19.74	10.51	2.12	24.25	53.57	54.98
2021	-20.91	-9.29	-9.84	-19.55	10.76	2.76	33.38	57.12	58.55
2022	-19.90	-7.98	-8.62	-18.43	12.44	4.36	51.64	70.54	72.10
2023	-45.14	-33.29	-33.24	-44.41	-27.16	-25.58	-57.72	-55.72	-55.53
2024	-32.60	-19.60	-19.92	-31.45	-7.76	-9.38	-19.49	-17.81	-17.25
2025	-26.09	-12.77	-13.38	-24.66	2.59	-1.22	22.27	20.05	21.02
2026	-36.76	-23.21	-23.50	-35.67	-14.24	-13.61	-29.34	-32.42	-32.03
2027	-32.46	-18.42	-18.91	-31.16	-7.48	-7.90	-6.70	-14.64	-14.07
2028	-28.90	-14.54	-15.22	-27.41	-1.81	-3.23	20.28	5.36	6.14
Period 2002-2010	-6.61	-4.10	-3.74	-6.20	27.96	27.96	3.44	27.97	263.41
Period 2011-2020	-17.23	-8.77	-8.98	-16.20	16.39	16.39	21.95	21.47	109.64
Period 2021-2028	-29.31	-17.81	-16.99	-28.05	-2.46	-2.46	4.29	9.56	10.43
Period 2002-2028	-17.72	-9.61	-9.90	-16.80	13.96	13.96	9.89	19.67	127.83
Total change 2002-2028 Base 67.77%	*19.28*	*43.08*	*43.08*	*21.77*	*20.41*	*43.65*	*129.35*	*5.07*	*-63.00*

Source: Own work.

Table D14. **Olives and vineyards production**

(*Variation in each year compared to benchmark scenario*)

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7 -Linear**	**Scenario 7 -Tiered**	**Scenario 7-High**
2002	0.00	-0.19	0.00	-0.33	0.00	1.52	-0.89	2.71	-12.41
2003	0.06	0.24	0.39	-0.20	4.64	1.97	1.19	3.16	-13.49
2004	0.47	1.00	1.11	0.30	5.06	2.73	3.30	3.53	-15.84
2005	-12.43	-11.14	-10.64	-12.57	-7.44	-9.29	-19.25	-16.25	-8.14
2006	-5.25	-3.74	-3.61	-5.30	-0.45	-1.86	-4.33	-2.75	-3.98
2007	-2.12	-0.45	-0.46	-2.07	2.58	1.40	2.29	2.53	-9.27
2008	-7.38	-5.02	-4.91	-7.30	-2.48	-3.09	-5.38	-5.51	-3.16
2009	-5.10	-2.55	-2.59	-4.93	-0.27	-0.62	-0.29	-0.98	-4.30
2010	-3.35	-0.68	-0.81	-3.10	1.43	1.26	2.56	2.11	-7.52
2011	-5.70	-2.50	-2.61	-5.40	-0.82	-0.51	0.48	0.85	-3.91
2012	-5.64	-2.17	-2.33	-5.28	-0.75	-0.16	1.11	1.13	-4.10
2013	-5.14	-1.48	-1.70	-4.70	-0.26	0.55	1.84	1.57	-4.99
2014	-19.60	-14.75	-14.35	-19.30	-14.57	-12.78	-19.40	-19.19	-14.65
2015	-11.94	-7.07	-7.12	-11.47	-6.87	-4.98	-5.57	-5.91	-3.91
2016	-8.35	-3.57	-3.85	-7.76	-3.36	-1.45	-0.06	-0.33	-2.34
2017	-14.35	-8.79	-8.82	-13.81	-9.25	-6.67	-7.76	-9.15	-5.93
2018	-11.85	-6.23	-6.45	-11.20	-6.77	-4.07	-3.25	-4.64	-3.08
2019	-9.87	-4.24	-4.61	-9.12	-4.82	-2.05	-0.60	-1.35	-2.01
2020	-12.57	-6.44	-6.72	-11.83	-7.47	-4.23	-3.14	-2.72	-3.23
2021	-12.54	-6.20	-6.54	-11.74	-7.43	-3.98	-2.66	-2.48	-3.00
2022	-12.00	-5.53	-5.94	-11.13	-6.90	-3.28	-1.79	-1.90	-2.43
2023	-27.09	-19.90	-19.55	-26.53	-22.31	-17.91	-24.04	-23.44	-23.70
2024	-19.43	-12.02	-12.13	-18.64	-14.37	-9.81	-10.85	-10.69	-11.06
2025	-15.66	-8.28	-8.66	-14.72	-10.55	-5.98	-4.81	-4.92	-5.36
2026	-21.98	-14.12	-14.18	-21.17	-17.00	-11.92	-13.76	-14.26	-14.58
2027	-19.44	-11.47	-11.74	-18.51	-14.40	-9.19	-9.14	-9.89	-10.25
2028	-17.40	-9.37	-9.82	-16.36	-12.32	-7.03	-5.84	-6.54	-6.94
Period 2002-2010	-3.90	-2.79	-2.39	-3.95	0.34	0.34	-2.31	-1.27	-8.68
Period 2011-2020	-10.27	-5.72	-5.76	-9.78	-5.27	-5.27	-3.69	-4.11	-4.99
Period 2021-2028	-17.57	-11.13	-10.59	-16.74	-12.53	-12.53	-8.45	-8.54	-8.95
Period 2002-2028	-10.58	-6.17	-6.25	-10.15	-5.82	-5.82	-4.82	-4.64	-7.54
Total change 2002-2028 Base 67.77%	*38.58*	*52.34*	*52.34*	*40.80*	*41.36*	*53.64*	*59.39*	*52.67*	*78.25*

Source: Own work.

Table D15. **Total Exports**

(*Variation in each year compared to benchmark scenario*)

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7 -Linear**	**Scenario 7 -Tiered**	**Scenario 7-High**
2002	0.00	-0.16	-0.07	-0.17	0.16	0.13	-0.04	0.29	0.39
2003	0.00	-0.13	-0.01	-0.14	0.19	0.20	0.14	0.39	0.44
2004	0.04	-0.06	0.08	-0.07	0.27	0.30	0.36	0.52	0.53
2005	-1.11	-1.21	-1.04	-1.22	-0.93	-0.87	-1.29	-1.19	-0.89
2006	-0.54	-0.59	-0.40	-0.60	-0.28	-0.18	-0.33	-0.25	-0.04
2007	-0.25	-0.27	-0.07	-0.28	0.05	0.18	0.26	0.28	0.34
2008	-0.73	-0.74	-0.51	-0.74	-0.44	-0.28	-0.42	-0.43	-0.20
2009	-0.54	-0.51	-0.27	-0.52	-0.20	-0.02	0.00	-0.06	0.10
2010	-0.38	-0.32	-0.07	-0.33	-0.01	0.20	0.36	0.27	0.33
2011	-0.60	-0.53	-0.25	-0.53	-0.21	0.02	0.10	0.18	0.10
2012	-0.60	-0.50	-0.22	-0.51	-0.19	0.06	0.19	0.24	0.15
2013	-0.57	-0.43	-0.14	-0.44	-0.12	0.15	0.34	0.35	0.23
2014	-1.67	-1.55	-1.26	-1.56	-1.30	-1.03	-1.31	-1.31	-1.32
2015	-1.14	-0.98	-0.65	-0.98	-0.69	-0.37	-0.42	-0.45	-0.45
2016	-0.86	-0.66	-0.33	-0.67	-0.36	-0.02	0.11	0.05	0.01
2017	-1.33	-1.13	-0.79	-1.13	-0.84	-0.50	-0.58	-0.66	-0.65
2018	-1.15	-0.91	-0.56	-0.92	-0.62	-0.26	-0.21	-0.32	-0.32
2019	-1.00	-0.73	-0.38	-0.74	-0.43	-0.05	0.10	-0.02	-0.05
2020	-1.22	-0.94	-0.57	-0.94	-0.64	-0.25	-0.18	-0.11	-0.33
2021	-1.22	-0.92	-0.55	-0.93	-0.62	-0.21	-0.12	-0.07	-0.28
2022	-1.19	-0.86	-0.48	-0.87	-0.56	-0.14	0.00	0.03	-0.18
2023	-2.20	-1.90	-1.58	-1.91	-1.67	-1.31	-1.54	-1.53	-1.72
2024	-1.73	-1.38	-1.01	-1.39	-1.12	-0.69	-0.76	-0.77	-0.97
2025	-1.48	-1.10	-0.71	-1.10	-0.81	-0.35	-0.28	-0.31	-0.51
2026	-1.91	-1.53	-1.16	-1.54	-1.27	-0.84	-0.94	-0.98	-1.17
2027	-1.76	-1.34	-0.96	-1.35	-1.07	-0.61	-0.62	-0.68	-0.87
2028	-1.63	-1.18	-0.79	-1.19	-0.90	-0.42	-0.35	-0.41	-0.61
Period 2002-2010	-0.39	-0.44	-0.26	-0.45	-0.13	-0.04	-0.11	-0.02	0.11
Period 2011-2020	-0.99	-0.82	-0.51	-0.83	-0.53	-0.22	-0.19	-0.22	-0.25
Period 2021-2028	-1.59	-1.24	-0.87	-1.25	-0.96	-0.53	-0.53	-0.54	-0.74
Period 2002-2028	-0.99	-0.84	-0.55	-0.84	-0.54	-0.26	-0.27	-0.26	-0.29
Total change 2002-2028 Base 67.77%	*65.04*	*66.05*	*66.56*	*66.05*	*65.98*	*66.85*	*67.25*	*66.58*	*66.11*

Source: Own work.

Table D16. **Total Imports**

(*Variation in each year compared to benchmark scenario*)

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7 -Linear**	**Scenario 7 -Tiered**	**Scenario 7-High**
2002	0.00	-0.17	-0.05	-0.17	0.06	0.04	0.13	-0.18	-2.15
2003	0.00	-0.13	0.00	-0.14	0.10	0.10	0.15	-0.16	-2.28
2004	0.03	-0.07	0.07	-0.07	0.16	0.18	0.19	-0.19	-2.52
2005	-0.87	-0.96	-0.79	-0.96	-0.71	-0.66	-0.75	-0.82	-0.84
2006	-0.38	-0.43	-0.25	-0.43	-0.19	-0.12	-0.25	-0.12	-1.10
2007	-0.16	-0.17	0.00	-0.18	0.07	0.15	0.00	0.03	-1.83
2008	-0.53	-0.52	-0.32	-0.52	-0.28	-0.16	-0.39	-0.18	-0.86
2009	-0.38	-0.33	-0.13	-0.33	-0.08	0.04	-0.22	0.03	-1.18
2010	-0.26	-0.17	0.02	-0.18	0.07	0.20	-0.08	0.13	-1.61
2011	-0.42	-0.31	-0.10	-0.32	-0.07	0.09	-0.25	-0.14	-1.12
2012	-0.42	-0.28	-0.06	-0.28	-0.03	0.14	-0.24	-0.12	-1.15
2013	-0.39	-0.22	0.00	-0.22	0.03	0.21	-0.19	-0.14	-1.28
2014	-1.37	-1.20	-0.92	-1.20	-0.96	-0.71	-1.18	-0.88	-0.98
2015	-0.86	-0.64	-0.38	-0.65	-0.39	-0.15	-0.67	-0.18	-0.58
2016	-0.62	-0.36	-0.11	-0.37	-0.11	0.13	-0.42	0.02	-0.76
2017	-1.03	-0.76	-0.47	-0.76	-0.51	-0.22	-0.82	-0.27	-0.56
2018	-0.86	-0.56	-0.28	-0.56	-0.30	-0.02	-0.65	-0.05	-0.51
2019	-0.73	-0.39	-0.12	-0.40	-0.13	0.14	-0.51	0.08	-0.58
2020	-0.92	-0.56	-0.27	-0.56	-0.30	0.01	-0.69	-0.19	-0.45
2021	-0.92	-0.17	-0.24	-0.53	-0.27	0.05	-0.69	-0.16	-0.43
2022	-0.88	-0.13	-0.18	-0.47	-0.21	0.12	-0.65	-0.16	-0.42
2023	-1.91	-0.07	-1.18	-1.52	-1.27	-0.89	-1.63	-1.05	-1.29
2024	-1.40	-0.96	-0.62	-0.95	-0.69	-0.31	-1.15	-0.35	-0.60
2025	-1.15	-0.43	-0.35	-0.66	-0.40	-0.02	-0.89	-0.11	-0.35
2026	-1.58	-0.17	-0.74	-1.09	-0.83	-0.42	-1.31	-0.49	-0.72
2027	-1.41	-0.52	-0.55	-0.89	-0.62	-0.21	-1.14	-0.25	-0.49
2028	-1.28	-0.33	-0.39	-0.72	-0.45	-0.04	-1.01	-0.09	-0.33
Period 2002-2010	-0.28	-0.33	-0.16	-0.33	-0.09	-0.02	-0.13	-0.16	-1.60
Period 2011-2020	-0.75	-0.53	-0.27	-0.53	-0.27	-0.04	-0.55	-0.19	-0.84
Period 2021-2028	-1.27	-0.82	-0.50	-0.82	-0.56	-0.19	-1.02	-0.32	-0.56
Period 2002-2028	-0.77	-0.56	-0.31	-0.56	-0.31	-0.09	-0.57	-0.22	-1.00
Total change 2002-2028 Base 67.77%	*65.63*	*66.85*	*67.19*	*66.85*	*66.91*	*67.63*	*65.86*	*67.91*	*70.89*

Source: Own work.

Table D17. **Exports by sectors**

(*Average variation in each period compared to benchmark scenario*)

	2002-2010					**2011-2019**					**2020-2028**				
	Sce 1	**Sce 6**	**Sce 7**			**Sce 1**	**Sce 6**	**Sce 7**			**Sce 1**	**Sce 6**	**Sce 7**		
			Linear	**Tier**	**High**			**Linear**	**Tier**	**High**			**Linear**	**Tier**	**High**
Cereals and legumes (irrigated land)	-30.68	-15.20	-13.33	-20.99	-63.38	-66.48	-43.60	-48.41	-48.24	-63.79	-85.86	-68.50	-70.78	-71.69	-71.46
Industrial crops (irrigated land)	-23.47	-7.50	-9.06	-8.30	-36.17	-52.55	-29.18	-30.16	-30.43	-38.80	-72.02	-50.95	-51.76	-52.29	-52.06
Fruit and vegetables (irrigated land)	-7.34	14.36	7.64	44.58	414.04	-18.95	9.01	38.56	38.01	176.73	-32.61	-1.07	15.21	23.58	25.18
Olives and vineyards (irrigated land)	-5.27	1.57	-2.75	2.08	4.05	-13.54	-1.79	-0.26	-1.28	4.73	-23.25	-7.81	-7.55	-7.27	-7.47
Non-irrigated agriculture	-2.68	-4.47	-4.37	-6.56	-28.86	-9.67	-10.74	-12.32	-12.49	-20.09	-17.41	-17.68	-18.53	-18.95	-19.77
Livestock	-4.63	-1.22	-1.97	-3.02	-23.83	-11.90	-3.67	-5.25	-5.47	-13.25	-20.73	-8.38	-9.49	-10.00	-10.82
Energy products	2.66	2.65	3.25	3.06	7.36	7.60	5.88	6.15	6.27	7.02	13.65	10.22	10.49	10.55	10.46
Water	0.89	1.74	0.74	0.97	-11.90	2.02	4.61	4.59	4.15	3.87	1.51	6.88	6.81	6.86	6.03
Minerals and metals	3.07	2.29	3.09	1.46	-8.64	8.45	6.28	5.36	5.48	1.02	14.35	11.25	10.83	10.58	10.23
Minerales and non-metals products	1.17	2.03	2.24	2.34	6.63	3.55	3.84	4.10	4.15	5.33	6.36	5.99	6.20	6.28	6.30
Chemicals	2.31	0.43	0.61	0.57	2.64	6.27	2.93	3.08	3.14	4.53	10.24	5.98	6.13	6.23	6.66
Mineral products, machinery and transport material	8.41	1.44	4.41	-0.55	-27.13	22.92	10.13	7.44	8.06	-5.26	39.54	22.26	21.05	20.29	20.00
Agri-food industry	-4.82	-0.47	-2.40	-1.80	-16.98	-12.51	-3.18	-3.85	-4.39	-7.78	-21.82	-8.41	-9.06	-9.31	-9.90
Manufactures	1.40	0.01	0.06	-0.08	-0.42	3.90	1.86	1.82	1.83	2.12	6.35	3.94	3.96	3.98	4.16
Rubber, plastics and others	2.49	0.23	0.76	0.56	5.04	6.99	2.65	2.87	3.02	4.37	12.22	5.93	6.20	6.29	6.84
Construction and engineering	0.77	2.36	2.37	2.09	-0.86	2.36	4.19	3.95	3.93	2.76	3.87	6.06	5.90	5.83	5.55
Hotels and restaurants	1.12	0.05	0.18	-0.70	-9.38	3.20	2.39	1.68	1.65	-1.79	5.07	4.81	4.37	4.16	3.69
Rest of services	0.75	0.43	0.49	0.24	-2.03	2.35	2.09	1.91	1.90	0.95	3.96	3.81	3.71	3.65	3.48
Standard deviation (%)	*9.61*	*5.66*	*4.87*	*12.29*	*102.09*	*21.91*	*13.64*	*17.35*	*17.31*	*46.92*	*31.02*	*22.30*	*23.22*	*23.89*	*23.95*

Source: Own work.

Table D18. **Imports by sectors**

(*Average variation in each period compared to benchmark scenario*)

	2002-2010					**2011-2019**					**2020-2028**				
	Sce 1	**Sce 6**	**Sce 7**			**Sce 1**	**Sce 6**	**Sce 7**			**Sce 1**	**Sce 6**	**Sce 7**		
			Linear	**Tier**	**High**			**Linear**	**Tier**	**High**			**Linear**	**Tier**	**High**
Cereals and legumes (irrigated land)	2.70	2.88	0.64	2.33	1.32	6.76	7.22	7.40	6.77	9.04	9.63	11.57	11.30	11.38	10.63
Industrial crops (irrigated land)	10.98	5.59	4.51	4.47	3.20	29.32	17.43	16.93	16.39	17.82	51.53	33.86	33.13	33.16	31.68
Fruit and vegetables (irrigated land)	-2.23	-3.89	-1.08	-7.51	-43.69	-5.63	-4.58	-8.54	-8.01	-26.11	-9.71	-6.33	-8.17	-9.26	-10.17
Olives and vineyards (irrigated land)	-1.79	-1.33	-0.40	-2.34	-16.68	-4.46	-1.62	-2.60	-2.54	-8.70	-7.78	-2.96	-3.31	-3.67	-4.29
Non-irrigated agriculture	-3.07	-0.37	-1.56	-1.18	-10.54	-7.82	-1.69	-2.10	-2.44	-4.64	-13.65	-4.68	-5.09	-5.26	-5.73
Livestock	-3.64	-0.28	-1.89	-0.98	-8.96	-9.39	-2.22	-2.39	-2.83	-3.84	-16.29	-6.07	-6.38	-6.48	-6.92
Energy products	-0.40	2.19	1.86	2.24	3.18	-0.72	2.89	3.02	2.93	3.52	-1.33	3.15	3.16	3.19	2.97
Water	0.59	0.59	0.59	0.59	0.59	1.93	1.93	1.93	1.93	1.93	3.29	3.29	3.29	3.29	3.29
Minerals and metals	0.21	1.91	1.88	2.69	12.33	1.12	2.73	3.42	3.44	6.43	2.43	3.62	4.01	4.18	4.26
Minerales and non-metals products	0.37	2.17	2.07	1.92	-1.05	1.32	3.67	3.46	3.41	2.29	2.13	5.04	4.88	4.80	4.50
Chemicals	0.20	0.66	0.49	1.18	7.53	0.92	1.72	2.24	2.21	4.65	1.59	2.63	2.91	3.05	2.99
Mineral products, machinery and transport material	3.05	1.29	2.23	0.70	-7.32	8.56	5.07	4.25	4.44	0.22	14.80	9.96	9.59	9.35	9.12
Agri-food industry	-0.89	-0.18	-0.50	0.00	2.81	-2.01	0.00	0.26	0.17	1.16	-3.30	-0.36	-0.26	-0.21	-0.56
Manufactures	0.66	0.24	0.25	0.03	-2.51	2.11	1.85	1.66	1.64	0.62	3.52	3.46	3.34	3.28	3.08
Rubber, plastics and others	1.20	0.79	1.06	0.24	-6.77	3.57	3.12	2.52	2.55	-0.60	6.05	5.70	5.35	5.16	4.75
Construction and engineering	0.41	2.37	2.27	2.15	-0.43	1.43	3.90	3.72	3.67	2.68	2.30	5.34	5.19	5.12	4.81
Hotels and restaurants	0.33	-0.23	-0.30	-0.22	-0.26	1.22	0.99	1.02	0.99	0.97	2.04	2.10	2.10	2.09	1.95
Rest of services	0.36	0.42	0.34	0.25	-1.97	1.30	1.75	1.60	1.57	0.74	2.15	2.98	2.87	2.81	2.62
Standard deviation (%)	*3.14*	*1.98*	*1.59*	*2.55*	*12.03*	*8.28*	*4.68*	*5.08*	*4.92*	*8.69*	*14.43*	*8.91*	*8.92*	*9.04*	*8.89*

Source: Own work.

Chapter 5

Uncertainty in water management

5.1. Introduction

A number of studies have highlighted the importance of dealing with uncertainty in both technological change and climate change in recent years (see Baker *et al.*, 2007 [13]; Baker and Shittu, 2008 [14]).

Uncertainty is a key issue for the design of climate change policies. The future is uncertain. The efficiency of innovations and the timing with which new advanced technologies are likely to become available are very difficult to estimate and, therefore, uncertain. Moreover, the availability of water resources is uncertain. In this context, economic policy measures to address the problems of water management must deal with the uncertainties surrounding the issue. Of course, it is no easy task to predict future water availability and drought, but the consequences of climate risks are enormously important. Moreover, the impact of events like drought persist even after they occur, affecting the behaviour of farmers and other agents, and influencing their decisions.

Computable general equilibrium models have been widely used in recent years to address the impacts of climate change and greenhouse gas (GHG) emissions (e.g. Harrison *et al.*, 2000 [91]; Gerlagh and Van der Zwaan, 2003 [80]; Dellink and Van Ierland, 2006 [51]; Böhringer *et al.*, 2009 [33]; González-Eguino, 2011 [86]), and also to address the management of water resources (e.g. Gómez *et al.*, 2004 [85]; Velázquez *et al.*, 2006 [183]; Berrittella *et al.*, 2007 [24]; Brower *et al.*, 2008 [37]; Van Heerden *et al.*, 2008 [182]). Specifically, the PACE (Policy Analysis Based on Computable

Equilibrium Model) model developed by Böhringer *et al*. (2002 [29]) has been used, with additional models, to assess the climate change and renewable energy targets set by the European Commission (2008 [70]) for 2020.

The use of these complex models has become possible due to advances in mathematical programming and software, which have made it easier to design structures rooted in economic reality to reflect modellers' objectives and common sense of policy-making in order to arrive at viable conclusions.

This thesis simultaneously addresses two objectives with regard to uncertainty. On the one hand we assess whether the inclusion of stochastic elements in CGE models has a role to play in water policy design, and on the other, we consider what are the key uncertainties that need to be addressed. For these purposes we develop a dynamic computable general equilibrium model which includes stochastic programming, providing an approximation to a dynamic stochastic general equilibrium (DSGE) model. The main features of this model are described in chapter 2, section 2.4.7.2.

This chapter addresses several key issues for the inclusion of uncertainty. First, uncertainty is included in the forecast of future water availability. Second, we include uncertainty in the timing of enhancements in the efficiency of irrigation water use derived from a policy of modernisation. This analysis considers the possibility that gains will never reach a level of advanced efficiency. Third, we incorporate stochastic elements in the sensitivity analysis.

The main contribution of this work, then, is to define a dynamic computable general equilibrium model that includes stochastic programming, in order to assess the influence of more than one uncertainty in water policy analysis at the same time. As far as we are aware, very few studies have so far incorporated uncertainty in computable general equilibrium models in this area, as explained in section 2.1.3 of chapter 2 (see, Böhringer and Rutherford, 2006 [31], and Pratt *et al*. 2013 [146], among others). Furthermore, none of these studies refer to Spain and none account for more than one uncertainty.

To sum up, this chapter complements the previous chapter, providing an analysis of some possible uncertainties affecting water management and the strategies proposed above and allowing us to evaluate the robustness of the results obtained from the model described in chapter 4. However, this model differs from the one applied in the previous chapter in several key ways. First, it has an intertemporal dynamic following Ramsey. Second, we assume the trend in the volume of water supplied to the Upper Aragon

Irrigation Scheme as a guide for the evolution of alternative water availabilities in order to smooth the cycle stiffness of the fourth chapter, avoiding the irregular evolution observable in chapter 4. Even where the results differ in quantitative terms, we expect to obtain the same trends and similar results from the previous simulations.

Section 2 of this chapter presents the uncertainties tackled, and scenarios and results are addressed in section 3.

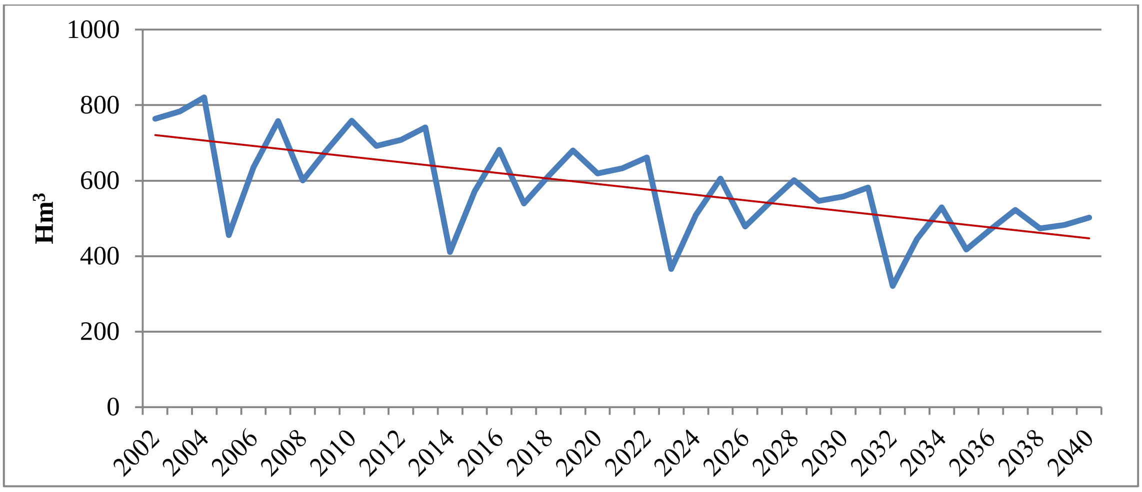
5.2. Uncertainties addressed

In this section we present three approaches which we consider may be of interest for the inclusion of uncertainty in the analysis of water management. (See programming codes in Appendix E).

Uncertainty 1

First, uncertainty is included in the projection of future water availability. To this end, we calculate the water supply trend in recent years (2002 to 2010). As we explained above, the actual evolution of water supply in this region over the last few years has followed a downward trend (see chapters 1 and 4), which would imply a 40% fall in the period 2040 (see Figure 5.1). However, a less drastic is also possible.

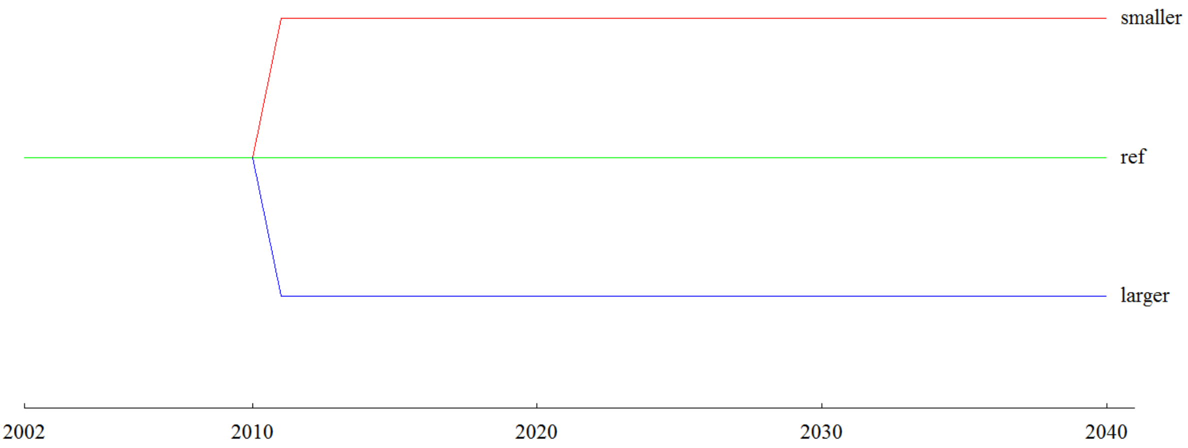
Figure 5.1. **Evolution of the irrigation water supply in Upper Aragon Irrigation Scheme**



Source: Own work.

Figure 5.2 represents the stochastic structure in an event tree via state transitions for the period 2011–2040. For the present purposes, we consider three states: a smaller decline in the water supply (20% fall by 2040), the reference trend (fall of 40% by 2040), and a larger decline (fall of 60% by 2040). A subjective probability is considered in which each state is equally likely.[47]

Figure 5.2. **Stochastic event tree (Uncertainty 1)**



Source: Own work.

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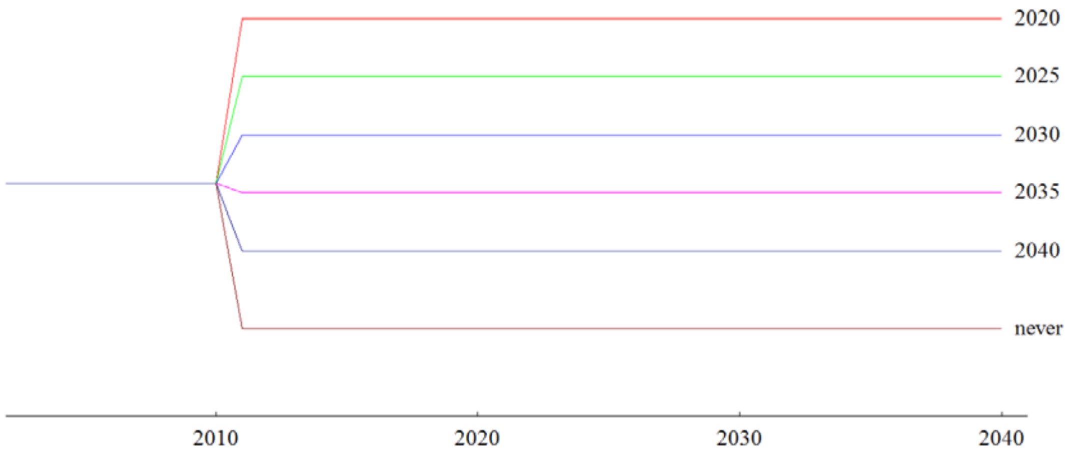
[47] Hence the model does not capture the full complexity of the problem, and the probability assumptions were chosen *ad hoc* and are not based on a thoroughgoing analysis. We leave these questions open for future research.

Uncertainty 2

The second uncertainty refers to the date at which advanced technology becomes available. We simulate a policy of irrigation modernisation which assumes an improvement in water use efficiency, as in Scenario 3 of chapter 4. An annual 25% markup is applied to water consumption costs by the new agent (*Farmer*) and receipts are earmarked to pay modernization costs as explained in chapter 4. We consider 80% efficiency to be a very advanced level. Based on our estimation of the Gompertz function (see section 2.4.8 in chapter 2) using data on the current modernization process, this level could be achieved by 2040. In the previous chapter, the time horizon ends in 2028, but in this chapter we extend it to 2040. Specifically, we assume 6 states of the world covering the date at which advanced technology will be achieved in the period 2020-2040. We also account for the possibility that no technological breakthrough will ever occur through an additional state of the world denoted by "*never*", which means the 80% level of efficiency will not be reached until after 2040.[48] Figure 5.3 displays the stochastic structure in an event tree representation via state transitions for the period 2011–2040. We include a discrete probability distribution (see Figure 5.4 and Appendix E for the programming of the event's probability). To sum up, the modernization process starts in 2011 in all cases, but the date at which a high level of efficiency is achieved varies as we reflected in the differing evolution of the Gompertz function for each state in Figure 5.5.

Figure 5.3. **Stochastic event tree (Uncertainty 2)**



Source: Own work.

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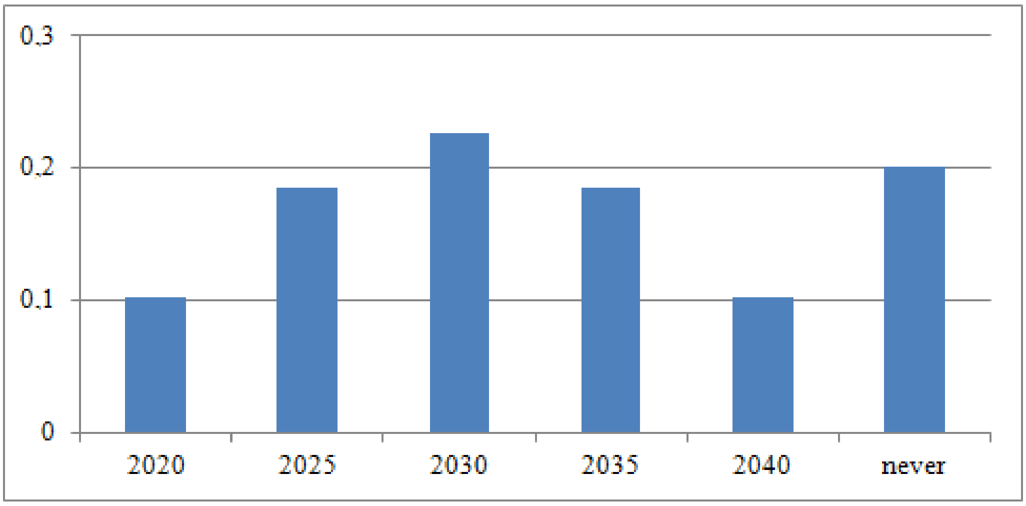
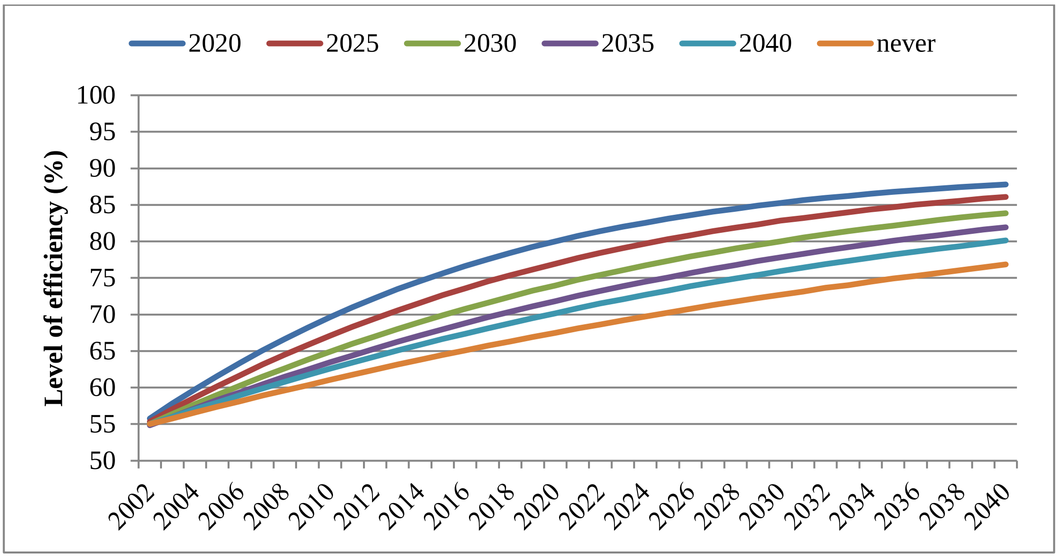
[48] Specifically, we assume that it is reached in 2050.

Figure 5.4. **Probability of event (Uncertainty 2)**



Source: Own work.

Figure 5.5. **Evolutions of efficiency**

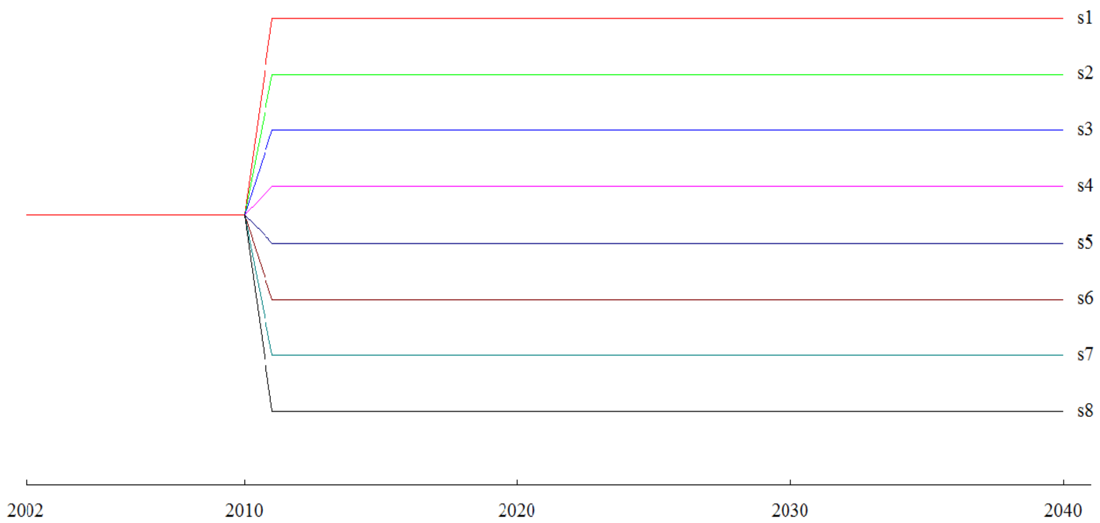


Source: Own work.

Uncertainty 3

As mentioned above, we assume that the elasticity of substitution between water and capital depends on the irrigation techniques used, taking values of 0.3, 0.2 and 0.1 depending on the type of crop (see section 2.4.9 in chapter 2). This value plays a key role in both results and policy implications. Thus, we analyse the robustness of the results using a wider range, from 0.1 to 0.8 (called s1–s8), allocating the same probability to each state of the world (Figure 5.6).

Figure 5.6. **Stochastic event tree (Uncertainty 3)**



Source: Own work.

5.3. Scenarios and Results

5.3.1. Description of scenarios

The following scenarios address the uncertainties presented in the previous section. They are designed to compare the relevance of these uncertainties in the analysis of economic policies.

- ***Scenario 1*****:** This scenario considers the uncertainty inherent in water availability (uncertainty 1).
- ***Scenario 2*****:** As well as considering the uncertainty of water availability, this scenario tackles the uncertainty affecting the date at which an advanced level of efficiency will be reached. The main aim is to mitigate the negative effects of a downward trend in the water supply through the modernisation of irrigation policy to improve the efficiency of water use. In other words, this scenario considers uncertainties 1 and 2 simultaneously.
- ***Scenario 3:*** We provide a sensitivity analysis of the main parameter used in the model to tackle uncertainty 3 (the elasticity of substitution between capital and

water factors). In this case, we assume that the water supply trend follows the observable trend, which drops by 40% in 2040, while the 80% level of efficiency is reached in 2040.

5.3.2. Initial results

This subsection presents the results of our simulations for scenarios 1 and 2. We show both the results of the main variable affected by water availability (output from irrigated agriculture) and the results of total output in Scenario 1 (Table 5.1) and Scenario 2 (Tables 5.2 and 5.3). To be more specific, Tables 5.1, 5.2 and 5.3 show the results for 2020, 2030 and 2040 to observe the evolution of both variables. Results are compared to a benchmark consisting of a steady state scenario, the economy for which is assumed to be on a balanced growth path. The results of the uncertainty in the sensitivity analysis (Scenario 3) are presented in the following subsection and in Table 5.4. Table 5.5 compares results with and without uncertainties in line with chapter 4. Specifically, we compare the results of the average for the third period analysed in the previous chapter (2020-2028), an additional period from 2029 to 2037, and the average of the overall period (2020-2040). Additional results are shown in Appendix E.

Observing Scenario 1, which includes the first uncertainty, it is apparent that the larger the decline in the volume of water, the larger the negative impacts on the main variables observed, and in particular on output from irrigated agriculture, as we expected. The differences between the alternatives and the reference state of the world grow larger over time and vary in each state of the world. Specifically, a larger decline in the volume of water produces a larger gap with respect to the reference decline (40% fall by in 2040) than a smaller decline would. As can be seen, the falls in output from irrigated agriculture are significant. Moreover, spillover effects in total production also become increasingly relevant over time. The falls in other variables are also larger, e.g. falls in rest of farming production, which depends on irrigated agriculture (see Table E1 in Appendix E).

Table 5.1 also shows the expected values according to the assumed probabilities. As expected, results are very similar to the results obtained from the “reference trend” because the probabilities are equal for the three states.

Table 5.1. **Results of Scenario 1: Uncertainty 1**

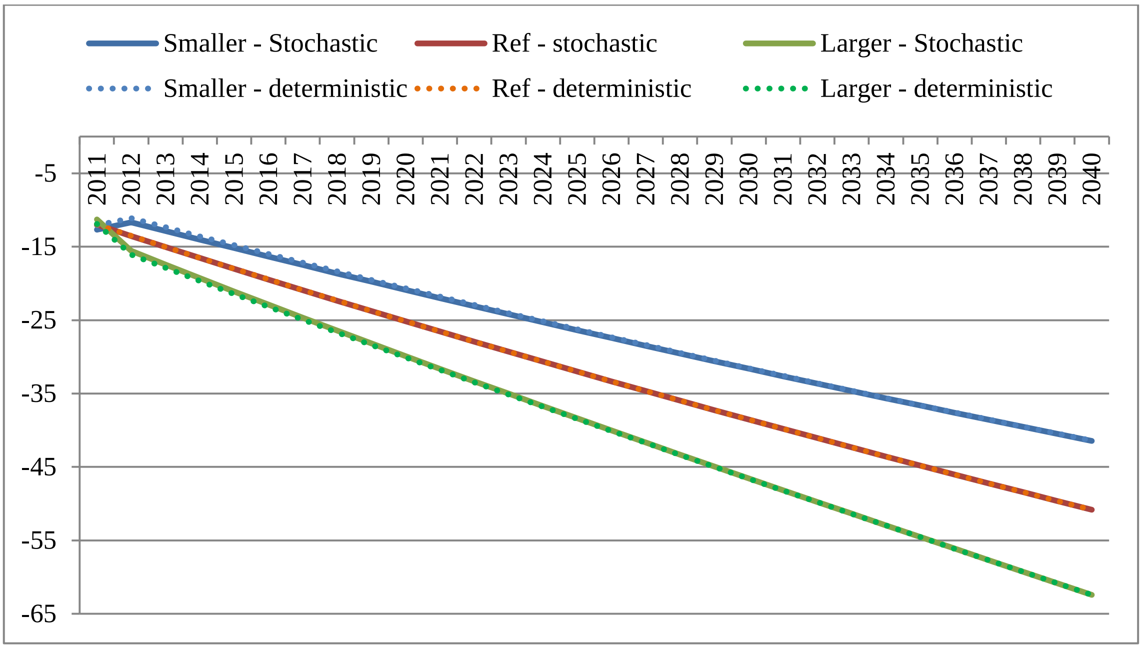
(*% change compared with benchmark*)

Variables	**States of the world**	**Years**		
		2020	**2030**	**2040**
Irrigated agriculture production	**Smaller decline**	**-20.89**	**-31.61**	**-41.43**
	Difference between smaller and reference decline	*4.28*	*6.93*	*9.38*
	Reference trend	**-25.17**	**-38.54**	**-50.82**
	Difference between reference and larger decline	*4.75*	*8.01*	*11.59*
	Larger decline	**-29.91**	**-46.54**	**-62.40**
	Interval size between smaller and larger decline	*9.03*	*14.94*	*20.97*
	Expected values	-25.32	-38.90	-51.55
Total production	**Smaller decline**	**-2.65**	**-3.76**	**-4.78**
	Difference between smaller and reference decline	*0.46*	*0.78*	*1.08*
	Reference trend	**-3.12**	**-4.55**	**-5.85**
	Difference between reference and larger decline	*0.54*	*0.96*	*1.42*
	Larger decline	**-3.65**	**-5.51**	**-7.27**
	Interval size between smaller and larger decline	*1.00*	*1.75*	*2.49*
	Expected values	-3.14	-4.61	-5.97

Source: Own work.

In order to shed light on the role of uncertainty in this scenario, Figure 5.7 shows the results of Scenario 1 for the three alternative evolutions of the water supply (a smaller decline, the reference trend and a larger decline) and for two approximations (deterministic and stochastic). Deterministic paths show the cases when agents know each specific evolution of the water supply with certainty. Stochastic paths show the results of Table 5.1 with equal subjective probability for each state. We can clearly observe the same path evolutions for both stochastic and deterministic cases.

Figure 5.7. **Comparative results of irrigated agriculture production for Scenario 1**



Source: Own work.

Scenario 2 addresses two uncertainties (1 and 2), and as shown in Tables 5.2 and 5.3 the inclusion of efficiency through a policy of modernization in the use of irrigation water mitigates negative impacts. The effect of technological improvements is obtained by comparing these results with those of Table 5.1 (see lower part of Table 5.2). In this case, the fall in the output of irrigated agriculture is reduced by around 16 difference points with Scenario 1 (without technical change) whatever the evolution of the water supply if the advanced level of efficiency is reached in 2020 (expected value). The reduction is around 11 difference points if advanced efficiency is achieved in 2040. Moreover, the relevance of the uncertainty is clear, as the difference points with Scenario 1 are higher regardless of the evolution of the water supply if technology advances soon.

The upper part of Table 5.2 reflects the influence of the date at which technology becomes advanced. Here we may observe that, the negative figures reflecting any downward trend in the water supply are smaller if technological progress is achieved is sooner rather than later.

As may be observed in the lower part of Table 5.2, meanwhile, the leaps from the year 2020 to 2030 are greater than the leaps from 2030 to 2040 in all rows (for all states at which advanced technology is achieved). This is because we assume a Gompertz evolution for technological change, and the function is in the decreasing phase. The effect is particularly noticeable when advanced technology is reached in 2020.

Table 5.2. **Results of irrigated agriculture production in Scenario 2: Uncertainties 1 and 2**

Years		**2020**				**2030**				**2040**			
Water		**smaller**	**ref.**	**larger**	**expected values**	**smaller**	**ref.**	**larger**	**expected values**	**smaller**	**ref.**	**larger**	**expected values**
						% change compared with benchmark							
Year at which technology becomes advanced	**2020**	-5.80	-9.95	-14.77	-10.17	-14.57	-21.89	-30.86	-22.44	-24.40	-34.92	-48.61	-35.98
	2025	-7.26	-11.46	-16.31	-11.68	-15.65	-22.99	-31.92	-23.52	-25.12	-35.62	-49.24	-36.66
	2030	-8.74	-12.99	-17.87	-13.20	-16.96	-24.31	-33.20	-24.83	-26.07	-36.54	-50.05	-37.56
	2035	-9.87	-14.15	-19.03	-14.35	-18.03	-25.38	-34.23	-25.88	-26.93	-37.37	-50.78	-38.36
	2040	-10.76	-15.06	-19.95	-15.26	-18.97	-26.32	-35.12	-26.80	-27.66	-38.16	-51.48	-39.10
	never	-12.29	-16.61	-21.50	-16.80	-20.67	-27.99	-36.72	-28.46	-29.32	-39.64	-52.78	-40.58
					-13.75*				-25.47*				-38.14*
						Difference points with Scenario 1 (without technical change)							
	2020	*15.09*	*15.21*	*15.14*	*15.15*	*17.04*	*16.64*	*15.69*	*16.46*	*17.03*	*15.90*	*13.79*	*15.57*
	2025	*13.63*	*13.70*	*13.60*	*13.65*	*15.96*	*15.55*	*14.62*	*15.37*	*16.31*	*15.20*	*13.17*	*14.89*
	2030	*12.15*	*12.17*	*12.05*	*12.12*	*14.65*	*14.22*	*13.34*	*14.07*	*15.36*	*14.27*	*12.35*	*13.99*
	2035	*11.02*	*11.02*	*10.89*	*10.98*	*13.58*	*13.15*	*12.32*	*13.02*	*14.50*	*13.45*	*11.62*	*13.19*
	2040	*10.12*	*10.11*	*9.96*	*10.06*	*12.64*	*12.22*	*11.42*	*12.09*	*13.77*	*12.66*	*10.92*	*12.45*
	never	*8.60*	*8.56*	*8.41*	*8.52*	*10.94*	*10.54*	*9.83*	*10.44*	*12.11*	*11.17*	*9.63*	*10.97*
					11.57				*13.43*				*13.41*

Source: Own work.

*Note: Expected value for each evolution of water supply whatever year at which technology becomes advanced.

Table 5.3 shows that spillover effects in total production are also reduced because of technological change (see the lower part of Table 5.3). If we observe sector results, falls in the rest of farming output are also considerably reduced, because this sector depends on irrigated agriculture (see Table E2 in Appendix E). Moreover, falls in industrial and services output are also smaller (see Tables E3 and E4 in Appendix E), and the same outcome is observable for the rest of the main variables in Appendix E (e.g. trade results).

Table 5.3. **Results of total production in Scenario 2: Uncertainties 1 and 2**

Years		**2020**				**2030**				**2040**			
Water		**lower**	**ref.**	**larger**	**expected values**	**lower**	**ref.**	**larger**	**expected values**	**lower**	**ref.**	**larger**	**expected values**
		% change compared with benchmark											
Year at which technology becomes advanced	**2020**	-1.24	-1.70	-2.25	-1.73	-2.14	-2.95	-3.99	-3.03	-3.11	-4.25	-5.82	-4.39
	2025	-1.34	-1.79	-2.35	-1.83	-2.22	-3.03	-4.07	-3.11	-3.16	-4.30	-5.87	-4.45
	2030	-1.44	-1.90	-2.46	-1.93	-2.32	-3.13	-4.17	-3.21	-3.24	-4.38	-5.95	-4.52
	2035	-1.52	-1.98	-2.54	-2.02	-2.40	-3.22	-4.26	-3.29	-3.31	-4.45	-6.01	-4.59
	2040	-1.59	-2.05	-2.61	-2.09	-2.48	-3.29	-4.33	-3.37	-3.38	-4.52	-6.07	-4.66
	never	-1.71	-2.18	-2.74	-2.21	-2.63	-3.44	-4.47	-3.51	-3.52	-4.66	-6.20	-4.80
					-1.98*				-3.26*				-4.58*
		Difference points with Scenario 1 (without technical change)											
	2020	*1.41*	*1.42*	*1.40*	*1.41*	*1.62*	*1.60*	*1.52*	*1.58*	*1.67*	*1.61*	*1.45*	*1.58*
	2025	*1.32*	*1.32*	*1.30*	*1.31*	*1.54*	*1.52*	*1.44*	*1.50*	*1.62*	*1.55*	*1.40*	*1.52*
	2030	*1.22*	*1.22*	*1.19*	*1.21*	*1.45*	*1.42*	*1.34*	*1.40*	*1.54*	*1.47*	*1.33*	*1.45*
	2035	*1.13*	*1.13*	*1.11*	*1.12*	*1.36*	*1.33*	*1.26*	*1.32*	*1.47*	*1.40*	*1.26*	*1.38*
	2040	*1.07*	*1.06*	*1.04*	*1.05*	*1.28*	*1.25*	*1.18*	*1.24*	*1.40*	*1.34*	*1.20*	*1.31*
	never	*0.94*	*0.94*	*0.91*	*0.93*	*1.14*	*1.11*	*1.04*	*1.09*	*1.26*	*1.19*	*1.07*	*1.17*
					1.16				*1.34*				*1.39*

Source: Own work.

*Note: Expected value for each evolution of water supply whatever year at which technology becomes advanced.

To sum up, a policy of irrigation modernisation should take the evolution of the process into account, because results may vary considerably. Meanwhile, the inclusion of stochastic elements in the date at which advanced technology becomes available lets us observe the effectiveness of the modernization policy under different conditions. Indeed, efforts to achieve technological improvements in the use of water could be entirely wasted depending on the timing of breakthroughs.

5.3.3. Uncertainty in the sensitivity analysis

Table 5.4 shows the effects of alternative values for the elasticity of substitution between the water and capital factors. As in the previous section, we assume a downward trend in the water supply leading to a fall of 40% by 2040, and a technological improvement in the use of water providing 80% efficiency by 2040.[49]

The variation in the results shows the sensitivity of the model to this parameter. As expected, if there is a high degree of substitutability, the negative impacts caused by the downward trend in the water supply will be less. This difference could be more than 12 points in over time.

Table 5.4. **Results of Scenario 3: Uncertainty 3**

(*% change compared with benchmark*)

Variables	States of the world	2020	2030	2040
Irrigated agriculture production	s1 (0.1)	-17.67	-29.91	-42.33
	s2 (0.2)	-16.58	-28.03	-39.77
	s3 (0.3)	-15.71	-26.42	-37.46
	s4 (0.4)	-15.02	-25.08	-35.43
	s5 (0.5)	-14.45	-23.97	-33.69
	s6 (0.6)	-13.99	-23.04	-32.22
	s7 (0.7)	-13.60	-22.26	-30.99
	s8 (0.8)	-13.27	-21.60	-29.95
Total production	s1 (0.1)	-2.21	-3.52	-4.82
	s2 (0.2)	-2.11	-3.34	-4.58
	s3 (0.3)	-2.03	-3.19	-4.37
	s4 (0.4)	-1.96	-3.06	-4.17
	s5 (0.5)	-1.91	-2.95	-4.00
	s6 (0.6)	-1.86	-2.86	-3.85
	s7 (0.7)	-1.83	-2.78	-3.73
	s8 (0.8)	-1.79	-2.72	-3.63

Source: Own work.

---

[49] We range the elasticity of substitution from 0.1 to 0.8. The elasticity values of assumed previously in this thesis, which cover a range from 0.1 to 0.3, reveal the difficulties inherent in substitution of these factors. Water transfers from one sector to another one can be complex if we take into account the inflexibility of urban and industrial water uses. Similarly, the water factor has a degree of exclusivity which means that this parameter will be closer to 0 (Leontief) than 1 (Cobb-Douglas).

However, the sensitivity analysis shows that the qualitative results are not fundamentally different, but that the size of effects can change substantially. From a policy perspective, the sensitivity of this parameter suggests that a policy designed to increase the substitution between capital and water may significantly contribute to mitigate the economic effects of water constraints. Indeed, the policy of irrigation modernization promotes change in this way.

Finally, Table 5.5 compares the influence of solving the model either as a recursive model (chapter 4) or as a fully inter-temporal optimization problem (chapter 5). In both cases, therefore, we only consider the alternative states when advanced technological improvement (80%) is achieved in 2040 and the downward trend in the water supply drops 40% by 2040.

The results for irrigated agriculture production are similar in both models. In other words, the results and conclusions obtained in chapter 4 are clearly robust. However, some macroeconomic results differ, in line with the results reported in the literature (see Babiker *et al.*, 2009 [12]) on the evaluation of differences between recursive and forward-looking models used in climate policy analysis. Specifically, the falls in total production are larger in the forward-looking version of the model. Total consumption results are similar in both models, but if we observe the production results for industrial sectors, we find differences between the two models.

This result is surprising and suggests that the treatment of capital stock in the recursive model (chapter 4) could probably be tweaked to take full advantage of the capacity for substitution between factors facing constraints (in this case, land and water). This might indicate that the recursive model offers a more realistic treatment and open up an avenue for future research. However, the aim of this study was to compare our previous results with an approximation to a dynamic stochastic general equilibrium model, and these are usually designed as forward-looking models. In any event, pervasive uncertainty, likely revision of policies over time, and unexpected changes in technology suggest the need for a stochastic solution, as Babiker *et al.* (2009 [12]) conclude.

Table 5.5. **Chapter 4 versus chapter 5**

Variable	Average for the period	With a recursive model and the current evolution of water supply (Chapter 4)		With a forward-looking model and the trend of the water supply (Chapter 5)	
		Downward water supply trend	With technological change	Downward water supply trend y	With technological change
Irrigated agriculture production	2020-2028	-30.43	-19.02	-30.62	-19.49
	2029-2037	-41.78	-28.74	-42.29	-29.86
	2020-2040	-37.49	-25.02	-38.34	-26.43
Total production	2020-2028	-1.28	-0.29	-3.70	-2.55
	2029-2037	-1.81	-0.57	-4.95	-3.67
	2020-2040	-1.61	-0.46	-4.53	-3.29
Total consumption	2020-2028	-0.33	-0.42	-0.37	-0.27
	2029-2037	-0.74	-0.38	-0.55	-0.37
	2020-2040	-0.59	-0.38	-0.50	-0.34
Industrial sectors ouput	2020-2028	1.51	1.87	-2.07	-1.62
	2029-2037	2.19	2.58	-2.46	-2.00
	2020-2040	1.93	2.32	-2.32	-1.85

Source: Own work.

5.4. Appendix E: Supplements to Chapter 5

5.4.1. Programming in GAMS

```
set
sw                      States of world
            /2020, 2025, 2030, 2035, 2040, never/

transition(t,sw,sw)     State transitions

/ 2010.2040.2020, 2010.2040.2025, 2010.2040.2030, 2010.2040.2035,
  2038.2040.never /;

********************************************************************************

parameter
pi(sw)          Period-by-period probability of efficiency improvement,

var             Variance in probability of event /0.2/;

pi(sw) = exp(-var * sqr(ord(sw)-card(sw)/2));
pi("never") = 0;
pi(sw) = 0.8 * pi(sw)/sum(sow,pi(sow));
pi("never") = 1 - sum(sw,pi(sw));

********************************************************************************
set
sx          States of world
               / smaller, reference, larger/

transitionx(t,sx,sx)     State transitions

/2010.reference.smaller, 2010.reference.larger/   ;

parameter
pi2(sx)          Period-by-period probability of water availability;


pi2(sx) = 1/card(sx);
```

Source: Own work based on Rutherford and Meeraus (2005 [158]).

5.4.2. Supplementary Tables

Table E1. **Scenario 1: Rest of results (Uncertainty 1)**

(*% change compared with benchmark*)

Variables	**States of the world**	**2020**	**2030**	**2040**
Rest of farming output	Smaller decline	-17.98	-27.99	-37.67
	Reference trend	-21.20	-33.96	-46.36
	Larger decline	-24.98	-41.38	-58.11
	Expected values	**-21.39**	**-34.44**	**-47.38**
Industrial output	Smaller decline	-1.61	-1.97	-2.24
	Reference trend	-1.86	-2.35	-2.68
	Larger decline	-2.16	-2.81	-3.23
	Expected values	**-1.88**	**-2.37**	**-2.72**
Services output	Smaller decline	-0.64	-0.84	-1.04
	Reference trend	-0.72	-1.02	-1.32
	Larger decline	-0.83	-1.27	-1.76
	Expected values	**-0.73**	**-1.04**	**-1.38**
Total Private Consumption	Smaller decline	-0.32	-0.42	-0.56
	Reference trend	-0.31	-0.48	-0.73
	Larger decline	-0.30	-0.59	-1.06
	Expected values	**-0.31**	**-0.50**	**-0.78**
Total Exports	Smaller decline	-1.96	-3.79	-5.50
	Reference trend	-1.93	-4.33	-6.47
	Larger decline	-1.79	-4.79	-7.42
	Expected values	**-1.89**	**-4.30**	**-6.46**
Total Imports	Smaller decline	-2.71	-3.76	-4.65
	Reference trend	-3.15	-4.44	-5.50
	Larger decline	-3.63	-5.21	-6.47
	Expected values	**-3.16**	**-4.47**	**-5.54**

Source: Own work.

Table E2. **Scenario 2: Rest of farming output**

Years		**2020**				**2030**				**2040**			
Water		**smaller**	**ref.**	**larger**	**expected values**	**smaller**	**ref.**	**larger**	**expected values**	**smaller**	**ref.**	**larger**	**expected values**
		% change compared with benchmark											
Year at which technology becomes advanced	**2020**	-7.43	-10.07	-13.34	-10.28	-15.04	-20.43	-27.59	-21.02	-23.83	-32.21	-44.41	-33.48
	2025	-8.27	-11.00	-14.34	-11.20	-15.75	-21.21	-28.43	-21.80	-24.35	-32.77	-44.98	-34.03
	2030	-9.16	-11.96	-15.38	-12.17	-16.63	-22.17	-29.45	-22.75	-25.05	-33.53	-45.75	-34.77
	2035	-9.84	-12.70	-16.18	-12.91	-17.37	-22.97	-30.29	-23.54	-25.69	-34.21	-46.43	-35.44
	2040	-10.40	-13.31	-16.83	-13.51	-18.03	-23.68	-31.03	-24.25	-26.31	-34.87	-47.09	-36.09
	never	-11.37	-14.35	-17.94	-14.55	-19.25	-24.98	-32.37	-25.53	-27.51	-36.13	-48.33	-37.33
					-12.55				-23.25				-35.27
		Difference points with Scenario 1 (without technical change)											
	2020	*10.55*	*11.12*	*11.64*	*11.11*	*12.95*	*13.53*	*13.78*	*13.42*	*13.84*	*14.15*	*13.70*	*13.90*
	2025	*9.71*	*10.20*	*10.64*	*10.18*	*12.24*	*12.75*	*12.95*	*12.65*	*13.32*	*13.59*	*13.13*	*13.35*
	2030	*8.83*	*9.24*	*9.60*	*9.22*	*11.36*	*11.78*	*11.93*	*11.69*	*12.62*	*12.84*	*12.37*	*12.61*
	2035	*8.14*	*8.49*	*8.80*	*8.48*	*10.62*	*10.99*	*11.09*	*10.90*	*11.98*	*12.16*	*11.69*	*11.94*
	2040	*7.58*	*7.89*	*8.15*	*7.87*	*9.96*	*10.28*	*10.35*	*10.20*	*11.36*	*11.50*	*11.03*	*11.29*
	never	*6.61*	*6.85*	*7.04*	*6.83*	*8.74*	*8.98*	*9.01*	*8.91*	*10.15*	*10.23*	*9.78*	*10.06*
					8.84				*11.19*				*12.11*

Source: Own work.

Table E3. **Scenario 2: Industrial output**

Years		**2020**				**2030**				**2040**			
Water		**smaller**	**ref.**	**larger**	**expected values**	**smaller**	**ref.**	**larger**	**expected values**	**smaller**	**ref.**	**larger**	**expected values**
		% change compared with benchmark											
Year at which technology becomes advanced	**2020**	-1.00	-1.31	-1.70	-1.34	-1.37	-1.83	-2.42	-1.87	-1.66	-2.21	-2.92	-2.27
	2025	-1.01	-1.32	-1.70	-1.34	-1.38	-1.84	-2.42	-1.88	-1.67	-2.22	-2.92	-2.27
	2030	-1.03	-1.33	-1.70	-1.35	-1.39	-1.85	-2.43	-1.89	-1.69	-2.23	-2.93	-2.28
	2035	-1.05	-1.35	-1.71	-1.37	-1.41	-1.86	-2.44	-1.90	-1.70	-2.24	-2.93	-2.29
	2040	-1.07	-1.37	-1.73	-1.39	-1.43	-1.88	-2.45	-1.92	-1.71	-2.25	-2.94	-2.30
	never	-1.11	-1.40	-1.75	-1.42	-1.48	-1.92	-2.47	-1.96	-1.76	-2.29	-2.96	-2.33
					-1.37				-1.90				-2.29
		Difference points with Scenario 1 (without technical change)											
	2020	*0.61*	*0.55*	*0.46*	*0.54*	*0.60*	*0.52*	*0.38*	*0.50*	*0.58*	*0.47*	*0.31*	*0.45*
	2025	*0.60*	*0.55*	*0.47*	*0.54*	*0.59*	*0.51*	*0.38*	*0.50*	*0.57*	*0.46*	*0.31*	*0.45*
	2030	*0.58*	*0.53*	*0.46*	*0.52*	*0.58*	*0.50*	*0.38*	*0.48*	*0.55*	*0.45*	*0.30*	*0.43*
	2035	*0.56*	*0.52*	*0.45*	*0.51*	*0.56*	*0.48*	*0.37*	*0.47*	*0.54*	*0.44*	*0.30*	*0.43*
	2040	*0.54*	*0.50*	*0.43*	*0.49*	*0.54*	*0.47*	*0.36*	*0.45*	*0.53*	*0.43*	*0.30*	*0.42*
	never	*0.50*	*0.46*	*0.41*	*0.46*	*0.49*	*0.43*	*0.33*	*0.42*	*0.48*	*0.39*	*0.27*	*0.38*
					0.51				*0.47*				*0.43*

Source: Own work.

Table E4. **Scenario 2: Services output**

Years		**2020**				**2030**				**2040**			
Water		**smaller**	**ref.**	**larger**	**expected values**	**smaller**	**ref.**	**larger**	**expected values**	**smaller**	**ref.**	**larger**	**expected values**
		% change compared with benchmark											
Year at which technology becomes advanced	**2020**	-0.44	-0.50	-0.60	-0.51	-0.56	-0.71	-0.95	-0.74	-0.70	-0.95	-1.35	-1.00
	2025	-0.43	-0.50	-0.60	-0.51	-0.56	-0.72	-0.95	-0.75	-0.71	-0.96	-1.36	-1.01
	2030	-0.43	-0.50	-0.60	-0.51	-0.57	-0.73	-0.97	-0.76	-0.72	-0.97	-1.37	-1.02
	2035	-0.44	-0.51	-0.61	-0.52	-0.59	-0.75	-0.99	-0.78	-0.74	-0.99	-1.40	-1.04
	2040	-0.44	-0.51	-0.61	-0.52	-0.59	-0.75	-0.99	-0.78	-0.74	-0.99	-1.40	-1.04
	never	-0.45	-0.52	-0.62	-0.53	-0.61	-0.78	-1.02	-0.80	-0.76	-1.02	-1.44	-1.07
					-0.52				-0.77				-1.03
		Differences with Scenario 1 (no technological change)											
	2020	*0.21*	*0.22*	*0.23*	*0.22*	*0.29*	*0.31*	*0.32*	*0.31*	*0.34*	*0.38*	*0.41*	*0.38*
	2025	*0.21*	*0.22*	*0.23*	*0.22*	*0.28*	*0.30*	*0.32*	*0.30*	*0.34*	*0.37*	*0.40*	*0.37*
	2030	*0.21*	*0.22*	*0.23*	*0.22*	*0.27*	*0.29*	*0.30*	*0.29*	*0.33*	*0.35*	*0.39*	*0.36*
	2035	*0.20*	*0.21*	*0.21*	*0.21*	*0.26*	*0.27*	*0.28*	*0.27*	*0.31*	*0.33*	*0.36*	*0.33*
	2040	*0.20*	*0.21*	*0.21*	*0.21*	*0.26*	*0.27*	*0.28*	*0.27*	*0.31*	*0.33*	*0.36*	*0.33*
	never	*0.19*	*0.20*	*0.20*	*0.20*	*0.24*	*0.25*	*0.25*	*0.24*	*0.28*	*0.30*	*0.32*	*0.30*
					0.21				*0.28*				*0.34*

Source: Own work.

Table E5. **Scenario 2: Total private consumption**

Years		**2020**				**2030**				**2040**			
Water		**smaller**	**ref.**	**larger**	**expected values**	**smaller**	**ref.**	**larger**	**expected values**	**smaller**	**ref.**	**larger**	**expected values**
						% change compared with benchmark							
Year at which technology becomes advanced	**2020**	-0.30	-0.26	-0.21	-0.26	-0.30	-0.31	-0.35	-0.32	-0.35	-0.43	-0.64	-0.47
	2025	-0.29	-0.25	-0.21	-0.25	-0.30	-0.31	-0.36	-0.32	-0.35	-0.44	-0.65	-0.48
	2030	-0.29	-0.25	-0.21	-0.25	-0.30	-0.32	-0.37	-0.33	-0.36	-0.45	-0.67	-0.50
	2035	-0.28	-0.24	-0.21	-0.24	-0.30	-0.32	-0.38	-0.34	-0.37	-0.47	-0.69	-0.51
	2040	-0.28	-0.24	-0.21	-0.24	-0.31	-0.33	-0.39	-0.34	-0.37	-0.48	-0.71	-0.52
	never	-0.27	-0.24	-0.21	-0.24	-0.31	-0.34	-0.41	-0.35	-0.39	-0.50	-0.74	-0.54
					-0.25				-0.33				-0.50
						Differences with Scenario 1 (no technological change)							
	2020	*0.02*	*0.05*	*0.08*	*0.05*	*0.12*	*0.18*	*0.25*	*0.18*	*0.21*	*0.30*	*0.42*	*0.31*
	2025	*0.03*	*0.05*	*0.09*	*0.06*	*0.12*	*0.17*	*0.24*	*0.18*	*0.21*	*0.29*	*0.41*	*0.30*
	2030	*0.04*	*0.06*	*0.09*	*0.06*	*0.12*	*0.16*	*0.22*	*0.17*	*0.20*	*0.28*	*0.39*	*0.29*
	2035	*0.04*	*0.06*	*0.09*	*0.06*	*0.12*	*0.16*	*0.21*	*0.16*	*0.19*	*0.27*	*0.37*	*0.28*
	2040	*0.05*	*0.06*	*0.09*	*0.07*	*0.11*	*0.15*	*0.20*	*0.16*	*0.18*	*0.25*	*0.36*	*0.26*
	never	*0.05*	*0.07*	*0.09*	*0.07*	*0.11*	*0.14*	*0.19*	*0.14*	*0.17*	*0.23*	*0.32*	*0.24*
					0.06				*0.16*				*0.28*

Source: Own work.

Table E6. **Scenario 2: Total exports**

Years		**2020**				**2030**				**2040**			
Water		**smaller**	**ref.**	**larger**	**expected values**	**smaller**	**ref.**	**larger**	**expected values**	**smaller**	**ref.**	**larger**	**expected values**
						% change compared with benchmark							
Year at which technology becomes advanced	**2020**	-0.43	-0.40	-0.25	-0.36	-1.60	-2.17	-2.72	-2.16	-3.17	-4.27	-5.49	-4.31
	2025	-0.55	-0.52	-0.38	-0.48	-1.72	-2.30	-2.85	-2.29	-3.27	-4.37	-5.58	-4.40
	2030	-0.66	-0.63	-0.49	-0.59	-1.89	-2.47	-3.02	-2.46	-3.40	-4.50	-5.70	-4.53
	2035	-0.74	-0.71	-0.57	-0.67	-2.02	-2.61	-3.15	-2.59	-3.53	-4.63	-5.82	-4.66
	2040	-0.79	-0.77	-0.63	-0.73	-2.14	-2.73	-3.26	-2.71	-3.66	-4.76	-5.94	-4.79
	never	-0.88	-0.86	-0.72	-0.82	-2.34	-2.93	-3.46	-2.91	-3.87	-4.96	-6.12	-4.98
					-0.62				-2.54				-4.63
						Differences with Scenario 1 (no technological change)							
	2020	*1.53*	*1.53*	*1.54*	*1.54*	*2.19*	*2.16*	*2.07*	*2.14*	*2.33*	*2.20*	*1.93*	*2.15*
	2025	*1.41*	*1.41*	*1.42*	*1.41*	*2.06*	*2.03*	*1.94*	*2.01*	*2.23*	*2.10*	*1.84*	*2.06*
	2030	*1.30*	*1.30*	*1.30*	*1.30*	*1.90*	*1.86*	*1.78*	*1.84*	*2.10*	*1.97*	*1.72*	*1.93*
	2035	*1.22*	*1.22*	*1.23*	*1.22*	*1.77*	*1.72*	*1.65*	*1.71*	*1.97*	*1.84*	*1.60*	*1.81*
	2040	*1.16*	*1.16*	*1.17*	*1.16*	*1.65*	*1.61*	*1.53*	*1.59*	*1.84*	*1.71*	*1.48*	*1.68*
	never	*1.07*	*1.07*	*1.08*	*1.07*	*1.45*	*1.40*	*1.33*	*1.39*	*1.63*	*1.51*	*1.30*	*1.48*
					1.27				*1.77*				*1.84*

Source: Own work.

Table E7. **Scenario 2: Total imports**

Years		**2020**				**2030**				**2040**			
Water		**smaller**	**ref.**	**larger**	**expected values**	**smaller**	**ref.**	**larger**	**expected values**	**smaller**	**ref.**	**larger**	**expected values**
		% change compared with benchmark											
Year at which technology becomes advanced	**2020**	-1.31	-1.77	-2.31	-1.79	-2.22	-2.99	-3.93	-3.05	-3.16	-4.19	-5.47	-4.27
	2025	-1.41	-1.87	-2.41	-1.90	-2.30	-3.07	-4.01	-3.12	-3.21	-4.24	-5.51	-4.32
	2030	-1.52	-1.98	-2.52	-2.01	-2.40	-3.16	-4.10	-3.22	-3.29	-4.31	-5.57	-4.39
	2035	-1.60	-2.07	-2.60	-2.09	-2.48	-3.25	-4.17	-3.30	-3.35	-4.37	-5.62	-4.45
	2040	-1.68	-2.14	-2.67	-2.16	-2.56	-3.32	-4.24	-3.37	-3.42	-4.43	-5.66	-4.50
	never	-1.80	-2.26	-2.79	-2.29	-2.70	-3.46	-4.36	-3.51	-3.55	-4.55	-5.76	-4.62
					-2.05				-3.27				-4.43
		Differences with Scenario 1 (no technological change)											
	2020	*1.41*	*1.38*	*1.32*	*1.37*	*1.54*	*1.45*	*1.28*	*1.42*	*1.49*	*1.32*	*1.00*	*1.27*
	2025	*1.31*	*1.28*	*1.22*	*1.27*	*1.46*	*1.37*	*1.21*	*1.35*	*1.44*	*1.27*	*0.96*	*1.22*
	2030	*1.20*	*1.17*	*1.11*	*1.16*	*1.36*	*1.27*	*1.12*	*1.25*	*1.37*	*1.20*	*0.90*	*1.15*
	2035	*1.11*	*1.08*	*1.02*	*1.07*	*1.27*	*1.19*	*1.04*	*1.17*	*1.30*	*1.14*	*0.85*	*1.10*
	2040	*1.04*	*1.01*	*0.95*	*1.00*	*1.20*	*1.12*	*0.98*	*1.10*	*1.24*	*1.08*	*0.81*	*1.04*
	never	*0.91*	*0.88*	*0.83*	*0.88*	*1.05*	*0.98*	*0.85*	*0.96*	*1.10*	*0.96*	*0.71*	*0.92*
					1.11				*1.20*				*1.11*

Source: Own work.

6. Conclusiones y Próximas investigaciones

6.1. Conclusiones

Ante la problemática actual del agua para riego en la provincia de Huesca, y en concreto, en la Comunidad General de Riegos del Alto Aragón, esta tesis se ha planteado la mejora en la gestión del agua de riego mediante la utilización de modelos de equilibrio general aplicado. Los modelos de equilibrio general aplicado han demostrado ser una herramienta útil para la gestión del agua de regadío y la recomendación de políticas económicas y medioambientales, pero siempre que sean diseñados de acuerdo a las características de la región de estudio y a los objetivos que se plantean. Esto nos ha llevado a desarrollar tres modelos de equilibrio general aplicado con distintas características de acuerdo a las simulaciones abordadas. La elección de las características del modelo depende siempre inicialmente de las simulaciones a realizar.

6.1.1. Capítulo 1

Este capítulo presenta e introduce el marco de análisis de la problemática que se va a abordar en la tesis. La información presentada y elaborada es la fuerza motriz que inspira los análisis y simulaciones realizadas en los capítulos siguientes. Más aún, esta información puede suscitar análisis adicionales para los próximos trabajos de investigación y para otros investigadores, tanto con un carácter más específico para pequeñas zonas de regadío de la Comunidad General de Riegos del Alto Aragón como para otros sistemas de regadío.

Una de las principales ideas que se extraen de este capítulo es que las comunidades de regantes pueden jugar un papel fundamental en la gestión del agua de regadío, ya que son los principales usuarios del agua regulada y obtienen sus rentas de los usos de ésta. En esta línea, una de las principales ventajas y características de esta tesis es que la información proporcionada por los propios agentes interesados en la gestión del agua de regadío, en este caso regantes, es tenida en cuenta para el diseño de escenarios que evalúan medidas de política económica y medioambiental. Esto ha sido posible gracias al contacto directo, la cercanía y la información proporcionada por la Comunidad General de Riegos del Alto Aragón. Por tanto, el análisis regional realizado tiene en este caso un alto realismo y permite aproximarse bien a la problemática que se aborda.

Este capítulo realiza un estudio de las demandas de agua, los niveles de eficiencia en el uso de agua para riego y la estructura de los cultivos y su rentabilidad para la Comunidad General de Riegos del Alto Aragón durante la primera década del siglo XXI. Esta comunidad se enfrenta a varios hechos: demandas crecientes por parte de los abastecimientos urbanos e industrias (demandas con menor elasticidad y mayor rigidez que las demandas de los agricultores, aunque menores), una evolución claramente decreciente del agua regulada suministrada a la CGRAA por la CHE, y una superficie regada en la CGRAA que crece cada año y que tiene una clara tendencia, de acuerdo con los planes existentes, de mantener ese crecimiento.

El agua suministrada a la CGRAA no ha crecido en los últimos 20 años pero sí lo ha hecho la superficie regada, lo que muestra que el agua se utiliza de forma más eficiente que en los ochenta y noventa, sólo así se puede regar más superficie con las mismas dotaciones. Del total de agua suministrada a la comunidad desde el embalse, una media del 85,77% es realmente utilizada en la comunidad. Esto refleja una baja pérdida de agua en el transporte a las parcelas, de sólo el 14,23%. Los resultados señalan una eficiencia total media en la CGRAA a lo largo de los diez años del 61%, que supone un nivel de eficiencia en baja medio del 72%. Todo ello representa un salto impresionante respecto a la situación de hace tres o cuatro décadas, se ha pasado de eficiencias inferiores al 45% a una eficiencia de más del 60%, pero además hay en estos momentos un proceso de modernización acelerado en el que ¾ de la superficie ya se han modernizado, pasando del riego por gravedad a riego localizado o por aspersión.

Sin embargo, dado el nivel de eficiencia alcanzado del 61%, con la dotación media a lo largo de la década de 6.973 m^3/ha se ha tenido una dotación neta (eliminadas las pérdidas) para la planta de 4.254 m³/ha que resulta insuficiente para cultivos como el maíz, el arroz, los cultivos industriales, la patata, la alfalfa, los frutales, el almendro o el viñedo. Si la eficiencia total se elevara al 70%, la dotación que se obtendría seguiría siendo insuficiente para el maíz, el arroz, la alfalfa, los frutales o el almendro. Esta insuficiencia se hará más grave a medida que la extensión de cultivo en regadío crezca.

En esta línea, los resultados obtenidos en el capítulo 1 muestran un cambio en los patrones de cultivo hacia productos menos exigentes de agua, como la cebada y el trigo, a pesar de que el maíz y la alfalfa han sido los principales y más rentables cultivos de la CGRAA y son esenciales para la industria agroalimentaria y la actividad ganadera. Ello se ha debido a diversas causas, pero quizás la más relevante ha sido la insuficiencia de las dotaciones de agua suministrada y la inseguridad en su suministro con la regulación actual. La política de la PAC, los cambios en los precios de venta y el encarecimiento de materias primas como abonos también han sido influyentes pero menos determinantes que los problemas de la falta de agua.

Este capítulo suscita varias recomendaciones: finalizar en el corto plazo los procesos de modernización, alcanzando en los próximos 10 ó 15 años la eficiencia total del 70%, aunque para ello se deban cofinanciar las transformaciones; nuevas regulaciones, ya que la garantía de agua para los riegos actuales es muy baja, pero limitadas a lo ya previsto (pantano de Biscarrués, Balsa de regulación de Almudévar,…) porque las capacidades de las cuencas del Gállego y Cinca están cerca de sus límites y también por los impactos medioambientales y sociales; consolidar el regadío existente, aumentar las garantías de suministro y crear algún tipo de regulación plurianual, con el fin de que cultivos como la alfalfa o el maíz, que son muy rentables y necesarios económicamente, vuelvan a recuperar su papel y no sean desplazados por cereales como el trigo o la cebada. Para llevar adelante estos cambios se necesita, sin lugar a dudas, el apoyo de los interesados y un cierto consenso social.

6.1.2. Capítulo 2

Este capítulo presenta la metodología abordada en la tesis: un modelo estático utilizado en el capítulo 3 y dos modelos dinámicos utilizados en los capítulos 4 y 5. Una conclusión que se extrae de este trabajo es que el sistema de lenguaje GAMS/MPSGE permite abordar con mayor facilidad el diseño y las características peculiares de cada modelo, así como incluir mejoras en los modelos de equilibrio general aplicado que permiten avanzar en su entendimiento, su acercamiento a la realidad, y la incorporación de novedades en la metodología y en los objetivos para evitar la común acusación de “caja negra”. La elección del modelo a diseñar depende principalmente de las preguntas a responder y de la región de estudio.

Un modelo de equilibrio general estático es más recomendable para el desarrollo de simulaciones que no aborden un horizonte temporal y estén centradas en evaluar medidas de cambios en el comportamiento de los agentes, cambios en los criterios de pago, medidas de responsabilidad compartida entre los usuarios, etc. El desarrollo de un buen modelo estático puede proporcionar más información y ayuda que un modelo dinámico según los objetivos del modelador.

Los modelos de equilibrio general dinámicos permiten incluir un horizonte temporal y tratan de responder a preguntas que permitan predecir cómo pueden afectar distintas medidas en el futuro, cercano o lejano, y con o sin cambios estructurales en la economía. En esta tesis, el diseño de un modelo dinámico ha sido de especial ayuda para la inclusión y análisis de una evolución de recursos hídricos que incluye años secos y años menos secos en el capítulo 4.

Por último, la inclusión de programación estocástica en el capítulo 5 permite abordar la incertidumbre en los modelos de equilibrio general aplicado. Los resultados de estas simulaciones muestran cómo cambian los resultados bajo diferentes opciones y simulaciones. En concreto, la inclusión de programación estocástica puede ser útil para abordar mejor determinadas simulaciones que incluyen interrogantes en el cambio tecnológico o en los problemas climáticos, aportando más información que con el uso del análisis de sensibilidad.

6.1.3. Capítulo 3

Este capítulo aborda los criterios de pago y la responsabilidad compartida en la gestión del agua de regadío en una región cuyos usos económicos del agua están muy próximos a sus máximos sostenibles. Este estudio trabaja con un modelo de equilibrio general aplicado estático que sigue el modelo del IFPRI como guía para la economía de la provincia de Huesca.

De acuerdo con la DMA y la reciente legislación española, los costes de la modernización deben ser pagados mayormente por los usuarios directos del agua, es decir, por los agricultores. Estos costes de la modernización son muy altos, suponiendo una carga a penas sostenible para los regantes, y sus respuestas han sido o bien abandonar la agricultura o intensificar los cultivos, aumentando la presión sobre los recursos hídricos.

En este capítulo, plateamos 5 diferentes criterios de distribución para el pago de esos costes. En dos de estos escenarios (1 y 2), los pagos fueron realizados únicamente por los usuarios directos. En el escenario 3 sólo pagaron los exportadores, y en el escenario 4 los hogares. El escenario 5 es una combinación de los escenarios anteriores. Los cinco escenarios fueron analizados en dos situaciones, con y sin aumento de la productividad agrícola.

Las principales conclusiones de este capítulo se basan en algunas cuestiones relevantes. En primer lugar, está claro que es necesario promover mejoras de la productividad para compensar los costes de la modernización, pero también para neutralizar los efectos económicos negativos globales de esos costes. Por otra parte, las mejoras de productividad hacen que los productos relacionados con la agricultura de regadío sean más baratos, aumentando así su demanda. Como consecuencia de ello, las caídas en las exportaciones encontradas en los escenarios sin mejoras de la productividad desaparecen o reducen su tamaño.

En segundo lugar, la distribución de pagos está lejos de ser una cuestión secundaria, ya que además tiene importantes consecuencias macroeconómicas y sociales que deben tenerse en cuenta en toda política ambiental del agua. Criterios de responsabilidad compartida mejorarían, sin duda, la viabilidad de las explotaciones existentes y reducirían la presión al alza de la demanda de agua causada por la modernización, más aún, genera efectos inflacionarios más pequeños y distorsiona menos los precios.

En tercer lugar, la aplicación de una política para compartir los costes del agua entre los usuarios directos, indirectos y finales es difícil. En el caso de los exportadores, probablemente habría que diferenciar entre productos, debido a que esta política (pagar por parte de los exportadores) podría causar problemas de competitividad, en concreto en el comercio con la Unión Europea. En el caso de los pagos por el agua virtual incorporada en el consumo (pagos por parte de los hogares), estos pagos sería similares a un impuesto ecológico que afectaría principalmente a los productos de la industria agroalimentaria y de la cuenta de Hoteles y restaurantes. Por otra parte, las variables hidrológicas, agronómicas y geográficas que afectan al agua virtual incorporada en los productos también necesitan ser consideradas. Aún así, ahora puede ser el momento para considerar la implantación de impuestos verde en proporción al agua virtual incorporada en los diferentes productos, en vistas a las conclusiones obtenidas de la actual investigación y de otros trabajos.

En cuarto lugar, si nos centramos en los efectos ambientales, el ahorro de agua es obtenido principalmente mediante las mejoras en el uso tecnológico, siendo los agricultores los principales responsables de este ahorro. Además, los ahorros logrados por los cambios en el consumo y en la exportación son social y culturalmente muy importantes, pero no tanto cuantitativamente. El 8,88% del ahorro de agua producido por la innovación tecnológica apenas varía con el sistema de reparto elegido. Este es un resultado crucial para la política del medio ambiente y la gestión del agua.

6.1.4. Capítulo 4

El uso de los modelos de equilibrio general aplicado es un nuevo enfoque en la integración de modelos hidro-económicos (Brower and Hofkes, 2008 [36]), por lo que hay una creciente literatura que utiliza estos modelos como herramienta para el análisis de la gestión del agua a través de diferentes políticas económicas. La mayoría de artículos publicados han abordado problemas como la relocalización del agua (Seung *et al*., 1998 [170]; Gómez *et al*., 2004 [85]), políticas de precios de agua (Decaluwé *et al*., 1999 [48]; Velázquez *et al*., 2006 [183]) y reducciones en la demanda de agua (Van Heerden *et al*., 2008 [182]), entre otros temas relevantes.

En este capítulo se aborda el tema de futuros cambios en la disponibilidad de agua para diseñar una estrategia capaz de mitigar los efectos a largo plazo de tendencias decrecientes del suministro de agua, incluso en años de sequía mediante un modelo de equilibrio general dinámico recursivo. Huesca, la región de regadío en la se centra este trabajo, se caracteriza por una tendencia a la baja del suministro de agua, con irregularidades en la disponibilidad de agua con años de gran sequía, así como también por la existencia de límites para la futura ampliación de la superficie total de cultivo. Por tanto, una exitosa política en esta región debe ser capaz de hacer frente a la severa escasez de agua en algunos años de sequía.

Las principales conclusiones de este capítulo son de amplio alcance. En primer lugar, el escenario 1 analizado en este capítulo revela significativos impactos negativos con caídas en los resultados macroeconómicos como consecuencia de las caídas en el volumen de agua y los límites en la extensión de tierra. No obstante, estos impactos son limitados en el conjunto de la economía, aunque son notables conforme pasa el tiempo y en los años de sequía. Efectos indirectos se observan también en otras cuentas, principalmente en la ganadería y en la industria agroalimentaria. Además, las variaciones en los precios del agua son importantes y los precios tienden a ser más altos en el largo plazo. El modelo pone además de manifiesto el abandono de las tierras por los agricultores en los años de sequía, lo que en la realidad se ha constatado en esta región.

En segundo lugar, los efectos de la disponibilidad futura de agua pueden ser controlados, a pesar de la presencia de sequías, mitigando la tendencia negativa de la economía a largo plazo a través de estrategias diseñadas para mejorar la tecnología en la agricultura de regadío. Se evalúan cuatro tipos de cambio tecnológico en agricultura. La mejora en la eficiencia del agua de riego muestra una gran capacidad para mitigar los impactos negativos sobre la producción de la agricultura de regadío. Sin embargo, invertir la tendencia requiere no sólo la mejora de la eficiencia del agua, sino también promover a los agricultores a realizar un buen uso de las oportunidades para obtener mejoras de productividad y lograr un uso óptimo de los recursos disponibles después de las inversiones en agricultura. Esto significa, por ejemplo, centrarse en los cultivos más rentables. El aumento de la innovación en la agricultura de regadío debería implicar un cambio en la evolución de los patrones de cultivo hacia los cultivos de regadío, como frutas y hortalizas, o como maíz y alfalfa, en lugar de cultivos de secano. Por otro lado, las simulaciones muestran que la clásica medida centrada en la extensión de las tierras de regadío no es ahora una buena alternativa ante la escasez de agua.

En tercer lugar, los resultados muestran que combinar mejoras tecnológicas con medidas de precios del agua de regadío podría ser una opción eficiente para los sectores de la agricultura de regadío, ya que un aumento gradual de los precios del agua de riego puede proporcionar una motivación adicional para un uso óptimo del agua hacia los cultivos más rentables (Frutas y hortalizas).

6.1.5. Capítulo 5

La introducción de programación estocástica para abordar la incertidumbre en la gestión del agua de riego en un modelo de equilibrio general computable permite corroborar algunas de las conclusiones obtenidas en el capítulo anterior. En primer lugar, la disponibilidad de los recursos hídricos determina significativamente los resultados. Cuanto mayor es la caída en el volumen de agua, mayores son los impactos negativos en la producción de la agricultura de regadío y en el resto de variables.

En segundo lugar, una política de modernización de riego a través de una mejora en el uso del agua reduce los efectos negativos, pero se ve afectada significativamente por la incertidumbre en el volumen de agua. En esta línea, cualquier esfuerzo para abordar la previsión de la disponibilidad de agua sería muy eficaz.

En tercer lugar, los beneficios de la mejora tecnológica también se podrían reducir por el retraso en la implementación de la tecnología avanzada. La fecha en la que la tecnología avanzada está disponible y es usada es realmente relevante. Los resultados negativos pueden reducirse a través de la tecnología en mayor o menor medida en función de la fecha en la que se aplica la nueva tecnología.

Finalmente, otra conclusión que se extrae de este trabajo es que la inclusión de la programación estocástica en los modelos de equilibrio general computable permite la aproximación a los modelos estocásticos, y como consecuencia revela hallazgos que no se obtienen directamente de un análisis de sensibilidad. Ello confirma que los modelos de equilibrio general computable pueden ser una herramienta poderosa y útil si se continúa su actualización y adaptación a los retos pendientes. Sin embargo, la fuerte demanda en los últimos años para hacer frente a la incertidumbre en las diferentes áreas debe ser también tratada con precaución. Cualquier conclusión puede verse afectada por incertidumbre, pero en la política económica y medioambiental, y en concreto en la gestión del agua, se requiere igualmente de afirmaciones y directrices claras.

6.2. Próximas investigaciones

A partir del trabajo realizado en esta tesis, la investigación más inmediata se centra en mejorar y ampliar dos aspectos que corresponden a los dos temas de la tesis: la gestión del agua de riego y la metodología.

Con respecto a la metodología, un primer trabajo en progreso es la construcción de un modelo de equilibrio general aplicado para un área más amplia y para un mayor número de regiones, en este caso, la economía de España, a partir de las tablas input-output de sus regiones. Esto implica aplicar a mayor escala y con modelización más compleja (por ejemplo, incluyendo el comercio interregional) todo el conocimieno adquirido en esta tesis en la modelización de una región. En particular, estamos trabajando en el diseño de un modelo de equilibrio general aplicado con la información proporcionada por un modelo multiregional input-ouput (MRIO en su acrónimo inglés) para España, teniendo en cuenta las 17 comunidades autónomas, además de la Unión Europea y el resto del mundo, obtenido de Cazcarro *et al*. (2013a [46]), que incluye el cálculo de los flujos de agua y huellas hídricas. Este modelo de equilibrio general aplicado basado en el MRIO para España está también desagregado en 40 sectores productivos para el año 2005.

El objetivo de este trabajo es la combinación de ambas herramientas para aprovechar las oportunidades ofrecidas por los dos modelos. Por un lado, el análisis MRIO ofrece conclusiones adicionales e implicaciones políticas en áreas claramente identificadas. En concreto, este análisis incluye la evaluación de la contribución de las cadenas de suministro a las presiones e impactos ambientales (Wiedmann y Barret, 2013 [187]). En esta línea, los modelos MRIO han llegado a ser comúnmente utilizados para medir y asignar la responsabilidad de impactos medioambientales, ver una revisión en Wiedmann (2009 [186]). Por otro lado, los modelos CGE incorporan un marco analítico más flexible para los análisis de escenarios debido a que pueden modelar el comportamiento de la oferta y la demanda, así como también los precios y las cantidades de forma simultánea y de manera endógena (Turner *et al*., 2008 [179]).

Una revisión de la literatura de modelos de equilibrio general aplicado sugiere varios aspectos que podrían ser mejoradas para su uso en el análisis económico, y en particular en el análisis regional, en primer lugar por ejemplo, la elasticidad de sustitución entre los inputs intermedios y los factores de producción. Los valores de esta pueden tener grandes repercusiones en los resultados del modelo y es crucial para determinar la intensidad de los efectos de los modelos de equilibrio general, ver el trabajo de Turner *et al*. (2012a [180]).

En segundo lugar, en la misma línea, análisis de sensibilidad deben realizarse para analizar la robustez de los resultados a los elementos de la especificación del modelo tales como el diseño de las funciones anidadas y la parametrización. Como ha señalado Dietzenbacher *et al.* (2013 [63]), en futuras investigaciones, es importante investigar cómo y en qué medida los resultados cambian para otros escenarios alternativos, es decir, es importante conocer el grado de sensibilidad de los resultados para distintos supuestos y situaciones.

En tercer lugar, tener en cuenta mecanismos de competencia imperfecta en el mercado de trabajo para analizar el desempleo puede ser importante para el caso de las regiones españolas. Por tanto, en las futuras investigaciones introduciremos una curva de salarios siguiendo el trabajo de Blanchflower y Oswald (1990 [27]) y la evidencia de la existencia de una curva de salarios en España (ver en detalle De Schoutheete, 2012 [54]; Sanromá y Ramos, 1999 [166]; Villaverde, 1999 [184]), que se corresponde también con la evidencia empírica para España de una relación inversa entre el nivel de los salarios reales y la tasa de desempleo.

En cuarto lugar, en función de las simulaciones a realizar, el horizonte temporal puede ser necesario. Los distintos enfoques dinámicos abordados en esta tesis pueden ser una primera aproximación para saber qué alternativa puede ser más precisa en cada caso. Por último, las reglas de cierre para un modelo MRIO-CGE así como la tecnología explícita e implícita de los inputs intermedios en el modelo requieren ser estudiados en detalle, especialmente para los estudios regionales.

En resumen, este trabajo en curso tiene como objetivo desarrollar un CGE basado en un MRIO para España en detalle con el fin de disponer de un modelo sólido para las simulaciones y análisis.

En cuanto al análisis de escenarios, algunas extensiones de esta tesis están en línea con las simulaciones abordadas. Por un lado, esta tesis ha realizado una primera aproximación al análisis de la responsabilidad compartida en el capítulo 3, en la gestión del agua de riego. En los últimos años, un creciente número de autores han estado examinando la responsabilidad del productor frente a la responsabilidad de los consumidores, con el fin de analizar cómo asignar la responsabilidad de las cuestiones ambientales (Lenzen *et al*., 2007 [107]). Difundir y mejorar esta primera aproximación, bajo un marco de un modelo multiregional input-ouput y un modelo de equilibrio general aplicado puede ayudar a proporcionar información, así como también plantear cuestiones basadas en la localización de las industrias más intensivas en agua o contaminantes (véase Turner *et al*., 2012b [181]). En esta línea, trabajos previos como los de Cazcarro *et al*. (2013a [46]) y Cazcarro *et al*. (2013b [47]) sobre huellas hídricas de las regiones españolas aportan resultados relevantes para el diseño de medidas de responsabilidad compartida.

En esta línea, trabajaremos también en el diseño de posibles medidas basadas en distintos criterios de relocalización de la producción mediante medidas tecnológicas y fiscales. Estas medidas tratan de proponer una mejora de la distribución de la producción según la distribución de los recursos naturales, y pueden proporcionar directrices en la toma de decisiones teniendo en cuenta los efectos económicos y medioambientales.

Más aún, en línea con los capítulos 1 y 3, intentaremos ampliar el acercamiento realizado en esta tesis para tener en cuenta la información de los agentes interesados (principalmente agricultores). Lograr una información para España similar a la usada en la tesis resulta realmente motivador. El reto es saber cómo mejorar la gestión del agua por los usuarios finales con un modelo multiregional vinculándolo al proceso participativo en línea con algunas trabajos previos como Prell *et al*. (2009 [147]), Reed *et al*. (2013 [151]), y Paavola y Hubacek (2014 [138]).

Por último, el análisis de los distintos cambios tecnológicos en la agricultura de regadío analizados en el capítulo 4 nos servirá de guía para entender las posibles consecuencias antes de elegir el cambio tecnológico más apropiado para cada cuestión, tanto para el agua como para otros recursos, como por ejemplo, la eficiencia energética, lo que sin duda es una línea de investigación prometedora.

6. Conclusions and Future research

6.1. General conclusions

Addressing the current issue of irrigation water in the province of Huesca and in the Upper Aragon Irrigation Scheme in particular, this thesis uses computable general equilibrium models to analyse improvements in irrigation water management. CGE models are a useful tool for irrigation water management and as a guide to economic and environmental policy, but they require careful design according to the characteristics of the region and the objectives proposed. In this light, we developed three CGE models with different features according to the simulations addressed, for the choice of a model's characteristics will always depend on the simulations performed.

6.1.1. Chapter 1

Chapter 1 presents and introduces the framework for the analysis of the problem addressed in the thesis. The information presented and developed provides the basis for the simulations described in the following chapters. Moreover, this information remains available for further analysis in future studies and for other researchers, whether focusing specifically on small irrigated areas in the Upper Aragon Irrigation Scheme or, in general, on other irrigation systems.

One of the main ideas to emerge from chapter 1 is that irrigation communities have a key role to play in the management of irrigation water, as they are the main users and obtain their income from the water uses. In this regard, one of the main advantages and features of this thesis is that information provided by farmers, who are key stakeholders in irrigation water management, is actually taken into account in the design of scenarios to evaluate economic and environmental policy measures. This has been possible due to direct contact, proximity and information provided by the Upper Aragon Irrigation Scheme. Therefore, the regional analysis is highly realistic, providing an ideal starting point to approach the problem.

Chapter provides a study of water demands, levels of efficiency in the use of water for irrigation, and cropping patterns in the CGRAA in the first decade of the twenty-first century. Meanwhile, the irrigation system itself faces a number of major issues, including rising urban and industrial demand for water (which, although considerably smaller, is less elastic and more rigid than agricultural demand); the downward trend in the water supplied to the CGRAA by the CHE; and the expansion of the irrigated area in the CGRAA coupled with plans to maintain this growth.

Water supply in the CGRAA has not grown in the last 20 years, but the irrigated area has increased, which shows that water is currently used more efficiently than in the 1980s and 1990s. This is the only reason why more land can be irrigated with same water endowments. An average of 85.77% of the total water supplied to the Upper Aragon Irrigation Scheme from reservoirs is actually used to water fields, reflecting low transport losses of only 14.23%. The results show a total efficiency of 61% on average in the CGRAA over the ten years considered in the study, which represents average field application efficiency of 72%. This implies a significant leap from the situation three or four decades ago, so that efficiency levels have risen from less than 45% to an over 60%. In addition, an intensive process of modernization has upgraded some ¾ of irrigated land from spray irrigation to drop and sprinkler irrigation.

However, given the 61% level of efficiency reached and average water allocation of 6,973m^3/ha over the decade, the net water allocation for plants (i.e. after losses are eliminated) was only 4,254 m^3/ha, which is insufficient for crops like maize, rice, industrial crops, potatoes, alfalfa, fruit trees, almonds and vineyards. Indeed, even if the total efficiency were raised to 70%, the water allocation would still be insufficient for maize, rice, alfalfa, fruit trees or almonds. This shortage will become ever more acute if and when irrigated cultivation is extended still further, as planned.

Chapter 1 shows a shift in cropping patterns to less thirsty plants like barley and wheat, even though maize and alfalfa have traditionally been the main and the most profitable crops in the CGRAA, and despite their importance to the agri-food industry and livestock sector. There are several reasons for this development, but the shortage of water is probably the most relevant. CAP subsidies, changes in sales prices and rising raw materials and fertilizer prices have also taken their toll, but these factors are in all cases less relevant than the lack of water.

Based on the information examined in chapter 1, a number of recommendations could be made. To begin with, finishing the modernisation process should be a priority so as to achieve 70% total efficiency in the next 10 or 15 years. However, the necessary transformations should be co-financed. New regulations are needed, because the available water supply for current irrigation is very insecure. However, new sources of supply should be limited to the infrastructure already planned (principally, the Biscarrués reservoir and Almudévar dam), because the Gallego and Cinca basins are close to their limits, and also because of the environmental and social impacts. The current irrigated area should be consolidated, increasing the security of the water supply and creating some kind of multiannual regulation, so as to encourage planting of crops like alfalfa and maize, which are very profitable and economically necessary, and ensure that they recover their role and survive displacement by cereals like wheat or barley. These changes will unquestionably need the support of stakeholders and a social consensus to take them forward.

6.1.2. Chapter 2

Chapter 2 presents the methodology applied in the thesis: a static model used in chapter 3 and two dynamic models used in chapters 4 and 5. One conclusion from this work is that the GAMS/MPSGE language system can easily be applied to the design and the characteristics of each model, as well as including improvements in order to advance our understanding of computable general equilibrium models, their approach to reality, and the incorporation of novelties in the methodology and objectives, avoiding the snare of “black box” modelling. The selection of each model depends mainly on the questions raised and the study region.

A static CGE model is advisable to develop simulations which do not require a time horizon and focus on evaluating changes in the behavior of agents, changes in payment criteria, shared responsibility measures among users, etc. The development of a good static model may provide more information and help than a dynamic model, depending on the objectives of the modeller.

Dynamic CGE models allow the inclusion of a time horizon, making it possible to answer questions in order to predict the effects of alternative measures in the short, medium and long run, with or without structural changes in the economy. In this thesis, the design of a dynamic model was used in chapter 4 to analyse the evolution of water resources, including dry years in differing areas of irrigated land.

Finally, the inclusion of stochastic programming in chapter 5 addresses uncertainty in CGE models. The results of these simulations show how the results change with alternative options and simulations. Specifically, the inclusion of stochastic programming can be useful to perform simulations under conditions of uncertainty with regard to technological change or climate issues, providing more information than could be obtained from the use of sensitivity analyses alone.

6.1.3. Chapter 3

This chapter addresses payment criteria and shared responsibility for irrigation water management in a region where economic uses of water are very close to the sustainable maximum. This study works with a static CGE model following the IFPRI model to provide a guide for the economy of Huesca province.

In accordance with the Water Framework Directive and recent Spanish legislation, the costs of modernization must be paid largely by direct water users, which is to say by farmers. However, modernization costs are very high, placing a barely sustainable burden on farmers, and their response has either been to abandon farming or to intensify cropping, increasing the pressure on water resources.

In this chapter, we assume 5 different distribution criteria for the payment of these costs. In two of these scenarios (1 and 2), payments are made only by direct users. In scenario 3 only exporters pay, and in scenario 4 only households. Scenario 5 combines the criteria employed in scenarios 2, 3 and 4. The five scenarios were examined in two situations, with and without agricultural productivity gains.

The main insights of this chapter are based on some relevant issues. First, it is clear that it will be necessary foster productivity gains not only to compensate for modernization costs, but also to neutralize their overall negative economic impacts. Moreover, productivity gains make products associated with irrigated farming cheaper, thereby boosting demand. As a consequence, the falling exports found when the scenarios were estimated without productivity gains either disappear or shrink.

Second, the distribution of payments is far from being a secondary matter, because it has important macroeconomic and social consequences that need to be taken into account in any environmental water policy. Shared responsibility criteria would certainly increase the viability of existing farms and would reduce the upward pressure on water demand caused by modernisation. Moreover, shared responsibility induces smaller inflationary effects and distorts prices less.

Third, applying a policy of sharing water costs among direct users, indirect users and end-users is difficult. In the case of exporters, the main problem would probably be to differentiate between products, because this policy (payments by exporters) could cause problems of competitiveness, in particular in trade with the European Union (EU). Meanwhile, payments for the virtual water embodied in consumption (payment by households) would be similar to a green tax which would mainly affect the products of the Agri-food industry and Hotels and restaurants. Moreover, the hydrological, agronomic and geographical variables affecting the virtual water embodied in products would also need to be taken into account. Even so, now may be the moment to consider the implementation of green taxes in proportion to the virtual water embodied in products, in light of the insights gleaned from this and other research.

Fourth, focusing on environmental effects, water savings are mainly produced by improvements in technological use, and farmers are the main agents of these savings. Furthermore, the savings achieved by changes in consumption and export patterns are socially and culturally very important, but less so quantitatively. The 8.88% of savings produced by technological innovation hardly varies with the sharing criteria applied. This is a crucial result for environmental policy and water management.

6.1.4. Chapter 4

The use of CGE models is a distinctive new approach to integrated hydro-economic modeling (Brower and Hofkes, 2008 [36]), and there is a growing literature which uses them as a tool for the analysis of water management through different economic policies. Most published papers tackle issues like the reallocation of water (Seung *et al.*, 1998 [170]; Gómez *et al.*, 2004 [85]), water pricing policies (Decaluwé *et al.*, 1999 [48]; Velázquez *et al.*, 2006 [183]) and reductions in water demand (Van Heerden *et al.*, 2008 [182]), among other topics.

This chapter addresses the issue of future changes in water availability so as to design a strategy able to mitigate the long-term effects of downward trends in water supplies, even in drought years, using a recursive dynamic CGE model. Huesca, the irrigation region on which this work focuses, is characterized by a downward trend in water supply and variable and irregular restrictions with very dry years, as well as limitations on any further expansion of the total area of farmland. Therefore, a successful policy in this regard must be able to cope with severe water constraints in some drought years.

The main insights of this chapter are wide-ranging. Firstly, Scenario 1 analysed in this chapter reveals significant impacts with negative macroeconomic results as a consequence of the downward trend in the water supply and limits on land expansion. Though such impacts are limited in the economy as a whole, they increase over time and in drought years. Spillover effects are also found in other accounts, mainly livestock and agri-food industry. Meanwhile, variations in water prices are significant and prices tend to be higher in the long-term. The model also shows the abandonment of land by farmers in drought years, a matter which this study had already verified based on the data obtained.

Secondly, the effects of future water availability can be managed, despite the presence of drought, reversing the long-term negative economic trend through strategies designed to improve technology in irrigated agriculture. Four alternative types of technological change are analyzed. The improvement in irrigation water efficiency displays significant great capacity to mitigate negative impacts on the production of irrigated agriculture. However, reversing the trend requires not only improved water efficiency but also encouraging farmers to make good use of opportunities to obtain productivity gains and achieve optimal use of the resources available after the investment in agriculture. This means, for example, focusing on the most profitable crops. Increasing innovation in irrigated agriculture should imply a shift in the evolution of cropping patterns towards irrigated crops, such as Fruit and vegetables and maize and alfalfa, instead of non-irrigated crops. On the other hand, the simulation shows that the former strategy, which focused on the extension of irrigated land, is no longer a good alternative given the existence of water constraints.

Thirdly, the results show that combining technological progress with irrigation water pricing could be an efficient option in irrigated agriculture sectors, because a gradual rise in irrigation water prices provides an extra incentive for optimal water use focusing on the most profitable crops (Fruit and vegetables).

6.1.5. Chapter 5

The inclusion of stochastic programming to address uncertainty in irrigation water management in a computable general equilibrium model highlights some conclusions pointed out in the previous chapter. First, the availability of water resources significantly determines results. The larger the decline in the volume of water the larger the negative impacts on the production of irrigated agriculture and the rest of variables.

Second, a policy of irrigation modernisation through an improvement in water use mitigates negative impacts, but it is significantly affected by the uncertainty in the volume of the water supply. In this line, efforts to address water availability forecasting would be highly effective.

Third, profits from improved technology could also be reduced if the implementation of an advanced technology is delayed. The date at which advanced technology becomes available and enters general use is very significant. Negative results can be reduced with technology to a greater or lesser extent depending on when a new technology is applied.

A final conclusion from this study is that the inclusion of stochastic programming in computable general equilibrium models allows an approximation to stochastic models, and as a consequence it reveals findings which cannot be obtained directly from a sensitivity analysis. Computable general equilibrium models could provide a powerful and useful tool if they continue to be updated and adapted to the outstanding issues. Nevertheless, the enthusiasm for addressing uncertainty in different areas should also be treated with caution. Any conclusions may be affected by uncertainty, but in economic and environmental policy, and specifically in water management, clear affirmations and guidelines are also required.

6.2. Future research

Starting from the work done in this thesis, the most immediate research goal will be to improve and expand on the management of irrigation water and methodology, two key themes of this thesis.

With respect to methodology, a first work in progress is the construction of a CGE model for an extended area and a larger number of regions, in this case, the economy of Spain, from input-output tables of its regions. This implies to apply all the acquired knowledge in this thesis for modelling one region to a larger scale and a complex modelling (e.g. including interregional trade). Specifically, we are working on the design of a CGE model for a multiregional input-output (MRIO) model for Spain, considering all 17 Spanish regions, plus the European Union and the Rest of the World obtained from Cazcarro *et al*. (2013a [46]), where the model is even extended to compute water flows and water footprints. This MRIO model is also broken down into 40 economic sectors for the year 2005.

The aim of this work is to combine both tools to take advantage of the opportunities offered by both models. On the one hand, MRIO analysis offers additional, policy-relevant insights into clearly identified areas. Specifically, this analysis includes an evaluation of the contribution of supply chains to overall environmental pressures and impacts (Wiedmann and Barret, 2013 [187]). In this regard, MRIO analyses have been increasingly used to measure and allocate responsibility for environmental impacts (see the review in Wiedmann, 2009 [186]). On the other hand, CGE models incorporate a more flexible analytical framework for scenario analyses because they can model both supply and demand side behaviour, prices and quantities simultaneously and endogenously (Turner *at al*. 2008 [179]).

A review of the CGE literature suggests several features which might be improved for use both in economic analysis and regional analysis, including for instance, the elasticity of substitution between intermediate inputs and factors of production. These values can have significant impacts on model output and they are crucial in determining the strength of general equilibrium effects (see Turner *et al*., 2012a [180]).

Second, sensitivity analyses need to be carried out on the robustness of results to elements of model specification like the design of nested functions and parameterization. As pointed out by Dietzenbacher *et al*. (2013 [63]), future research needs to investigate how and to what extent outcomes differ for alternative scenarios. In other words, it is important to know how sensitive the outcomes of the calculations are to the assumptions and initial situations used.

Third, consideration of imperfect competition mechanisms in the labour market to analyse unemployment would be important for the Spanish regions. The future research will also introduce a wage curve specification as an organizing framework following Blanchflower and Oswald (1990 [27]) and the evidence on the existence of a wage curve in Spain (see in detail De Schoutheete, 2012 [54]; Sanromá and Ramos, 1999 [166]; Villaverde, 1999 [184]), which corresponds to the empirical evidence for Spain on the inverse relationship between the level of real wages and the unemployment rate.

Fourth, a time horizon may be needed depending on the simulations performed. The alternative dynamic approaches tackled in this thesis provide an initial approximation, throwing light on the alternatives which may be the most accurate in each case. Finally, closure rules for a MRIO-CGE model, and the explicit and implicit technology of intermediate inputs in the model need to be addressed in detail, specifically for regional studies.

To sum up, this work in progress aims at developing a CGE based on the MRIO of Spain in detail to obtain a robust model for simulations and analyses.

As regards scenario analysis, some extensions of this thesis are in line with simulations addressed. On the one hand, chapter 3 of this thesis makes a first approximation to the analysis of shared responsibility in irrigation water management. In recent years, an increasing number of authors have been examining the nexus of producer versus consumer responsibility, often dealing with the question of how to assign responsibility for environmental issues (Lenzen *et al*., 2007 [107]). To extend and improve this initial approach with an interregional input–output and CGE modelling framework may help to provide information, as well as raising issues regarding the location of water-intensive or polluting industries (see Turner *et al*., 2012b [181]). In this regard, previous studies of the water footprints of Spain’s regions, such as Cazcarro *et al*. (2013a [46]) and Cazcarro *et al*. (2013b [47]), have contributed important results for the design of shared responsibility measures.

In this regard, we will also work on designing possible measures based on alternative production reallocation criteria through alternative technological and fiscal measures. These measures focus on improving production distribution in accordance with natural resources distribution, and may provide guidelines for decision-makers, as well as information about economic and environmental impacts.

In line with chapters 1 and 3, meanwhile, we will seek to extend the approach of seeking information from stakeholders (mainly farmers) taken in this thesis. Obtaining similar information for the whole of Spain is a very motivating task. The challenge is to learn how to improve water management by final users in a multiregional model, and how to link the participatory process, in line with existing studies such as Prell *et al*. (2009 [147]), Reed *et al*. (2013 [151]), and Paavola and Hubacek (2014 [138]).

Finally, the analysis of the alternative kinds of technological improvements in irrigated agriculture provided in chapter 4 will help us to understand the possible implications before choosing the best technical change for future analysis, both for water and other resources like energy. This line of research certainly looks very promising.

Bibliography

[1] AEAS. (2002) Encuesta de Tarifas 2002. Asociación española de Abastecimiento de Aguas y Saneamiento. Madrid. Cited on pages 104 and 150.

[2] AEMET. (2005) Resumen anual climatológico del año 2005. Agencia Estatal de Meteorología, Madrid. Cited on pages 25 and 55.

[3] Agenor, P.R., Izquierdo A., Tarp, H. (2009) Adjustment Policies, Poverty, and Unvemployment: The IMMPA Framewrok, Willey-Blackwell. Cited on page 99.

[4] Aguilera, F. (2006) Hacia una nueva economía del agua: Cuestiones fundamentales. Polis: revista académica de la Universidad Bolivariana, 14. Universidad de los Lagos, Osorno, Chile. Cited on page 103.

[5] Ahmed, N., Peerlings, J.H.M. (2009) Addressing Workers' Rights in the Textile and Apparel Industries: Consequences for the Bangladesh Economy, *World Development*, 37(3), 661–675. Cited on pages 4 and 12.

[6] Allan, J.A. (1993) Fortunately there are substitutes for water otherwise our hydro-political futures would be impossible. *ODA, Priorities for Water Resources Allocation and Management*, 13-26. Cited on page 147.

[7] Armington, P. (1969) A theory of demand for products distinguished by place of production. *International Monetary Fund Staff Papers*, 19, 159-178. Cited on pages 107 and 115.

[8] Arndt, C., Robinson, S., Willenbockel, D. (2011) Ethiopia's growth prospects in a changing climate: A stochastic general equilibrium approach, *Global Environmental Change*, 21(2), 701-710. Cited on page 98.

[9] Arrow, K.J., Debreu, G. (1954) Existence of an Equilibrium for a Competitive Economy, *Econometrica*, 22(3), 265-290. Cited on page 94.

[10] Atance, I., Barco, E., Benito, I., Compés, R., Langreo, A. (2006) La reforma de la Política Agraria Común: preguntas y respuestas en torno al futuro de la agricultura. Eumedia y Ministerio de Agricultura, Pesca y Alimentación, Madrid. Cited on pages 40 and 67.

[11] Baas, T., Brücker H. (2010) Macroeconomic impact of Eastern enlargement on Germany and UK: evidence from a CGE model, *Applied Economics Letters*, 17, 125–128. Cited on pages 4 and 11.

[12] Babiker, M.Gurgel, A., Paltsev, S., Reilly, J. (2009) Forward-looking versus recursive-dynamic modeling in climate policy analysis: A comparison, *Economic Modelling*, 26(6), 1341-1354. Cited on pages 95, 119 and 228.

[13] Baker, E., Clarke, L., Keisler, J., Shittu, E. (2007) Uncertainty, technical change, and policy models. Technical Report 1028. College of Management, University of Massachusetts, Boston. Cited on pages 97 and 215.

[14] Baker, E., Shittu, E. (2008) Uncertainty and endogenous technical change in climate policy models, *Energy economics*, 30(6), 2817-2828. Cited on pages 97 and 215.

[15] Balairón-Pérez, L. (2002) Gestión de recursos hídricos, *Ediciones UPB.* Barcelona. Cited on pages 2 and 10.

[16] Baldwin, R.E., François, J.F. (1999) Dynamic issues in applied commercial policy analysis, *Cambridge University Press*, Cambridge. Cited on pages 4 and 12.

[17] Ballard, C.L., Fullerton, D., Shoven, J.B., Whalley, J. (1985) A General Equilibrium Model for Tax Policy Evaluation, *University Chicago Press*, Chicago. Cited on pages 94 and 145.

[18] Banerjee, O., Alavalapati, J. (2009) A computable general equilibrium analysis of forest concessions in Brazil. *Forest Policy and Economics*, 11, 244–252. Cited on pages 4 and 12.

[19] Banse, M., van Meijl, H., Tabeau, A., Woltjer, G. (2008) Will EU biofuel policies affect global agricultural markets? *European Review of Agricultural Economics*, 35(2), 117–141. Cited on page 105.

[20] Barros, R., Isidoro, D., Aragüés, R. (2011) Long-term water balances in La Violada Irrigation District (Spain): II. Analysis of irrigation performance, *Agricultural Water Management*, 98(10), 1569-1576. Cited on pages 21, 40, 51 and 68.

[21] Bednaříková, Z., Doucha, T (2009) The impacts of agricultural policy scenarios on development of remote rural areas – the case study of the Bruntál and Ostrava districts, *Agricultural Economics*, 55(4), 161-168. Cited on pages 4 and 11.

[22] Berck, P., Robinson, S., Goldman, G.E. (1991) The use of computable general equilibrium models to assess water policies, *Department of Agricultural & Resource Economics, UC Berkeley*, 545. Cited on pages 96 and 149.

[23] Berrittella, M., Rehdanz, K, Roson, R., Tol, R.S.J. (2006) The economic impact of water pricing: a computable general equilibrium analysis, *Water Policy*, 10(3), 259-271. Cited on page 96.

[24] Berrittella, M., Hoekstra, A.Y., Rehdanz, K., Roson, R., Tol, R.S.J. (2007) The economic impact of restricted water supply: a computable general equilibrium analysis, *Water Research,* 41(8), 1799–1813. Cited on pages 96, 183 and 215.

[25] Bielsa, J., Cazcarro, I., Sancho, Y. (2011) Integration of hydrological and economic approaches to water and land management in Mediterranean climates: An initial case study in agriculture, *Spanish Journal of Agricultural Research,* 9(4), 1076-1088. Cited on pages 25 and 54.

[26] Birur, D.K., Hertel, T.W., Tyner, W.E. (2008) Impact of Biofuel Production on World Agricultural Markets: A Computable General Equilibrium Analysis, GTAP Working Paper No. 53. Cited on page 105.

[27] Blanchflower, D.G., Oswald, A.J. (1990) The Wage Curve, *Scandinavian Journal of Economics*, 92, 215-235. Cited on pages 248 and 259.

[28] Boeters, S., Veennendaal, P., van Leeuwen, N., Rojas-Romagoza, H. (2008) The potential for biofuels alongside the EU-ETS, Paper for presentation at the Eleventh Annual GTAP Conference 'Future of Global Economy', Helsinki, June 12-14. Cited on page 105.

[29] Böhringer, C., Löschel, A., Rohde, A. (2002) PACE - Policy analysis based on computable equilibrium, in: Forum für Energiemodelle und Energiewirtschaftliche Systemanalysen in Deutschland, *Energiemodelle zum Kernenergieausstieg in Deutschland*, Effekte und Wirkungen eines Verzichts auf Strom aus Kernkraftwerken, Umwelt und Ökonomie Bd. 34, Heidelberg, 436-450. Cited on pages 94 and 216.

[30] Böhringer, C., Löschel, A. (2006) Computable general equilibrium models for sustainability impact assessments: Status quo and prospects, *Ecological Economics,* 60, 49-64. Cited on page 94.

[31] Böhringer, C., Rutherford, T.F. (2006) Innovation, uncertainty and instrument choice for climate policy. Working Paper. Cited on pages 97 and 216.

[32] Böhringer, C., Löschel, A., Rutherford, T.R. (2007) Decomposing the integrated assessment of climate change, *Journal of Economics Dynamics & Control*, 31, 683-702. Cited on page 95.

[33] Böhringer, C., Löschel, A., Moslener, U., Rutherford, T.F. (2009) EU climate

policy up to 2020: an economic impact assessment. *Energy Economics*, 31(S2), S295–S305. Cited on pages 98 and 215.

[34] Briand, A. (2006) Marginal cost *versus* average cost pricing with climatic shocks in Senegal: a dynamic computable general equilibrium model applied to water. FEEM Working Paper No. 144.06. Cited on page 96.

[35] Brooke, A., Kendrick, D., Meeraus, A. (1998) GAMS: A User's Guide, *The Scientific Press*, New York. Cited on page 100.

[36] Brower, R. and Hofkes, M. (2008) Integrated hydro-economic modelling: Approaches, key issues and future research directions, *Ecological Economics*, 66(1), 16-22. Cited on pages 96, 99, 103, 180, 244 and 255.

[37] Brower, R., Hofkes, M., Linderhof, V. (2008) General equilibrium modelling of the direct and indirect economic impacts of water quality improvements in the Netherlands at national and river basin scale. *Ecological Economics*, 66(1), 127-140. Cited on page 215.

[38] Cadarso, M. A., López, L. A., Gómez, N., Tobarra, M. A., Zafrilla, J. E. (2009) International trade and shared environmental responsibility by activity sector. Application to the Spanish economy, Paper presented at the III Jornadas I-O de Albacete, Universidad de Castilla La Mancha. Cited on pages 6, 13 and 145.

[39] Calzadilla, A., Rehdanz, K., Tol, R.S.J. (2010) The economic impact of more sustainable water use in agriculture: A computable general equilibrium analysis, *Journal of Hidrology*, 384(3-4), 292-305. Cited on page 96.

[40] Cañada, A., Toledo, I. (2000) Leontief y España: una reflexión sobre las tablas Input/Output y su relevancia para la economía y los economistas españoles, *Historia y Pensamiento Económico ICE*, 789. Cited on page 97.

[41] Cardenete, M.A., Llop, M. (2005) Modelos multisectoriales de equilibrio general aplicado en España: una revisión, *Estudios de Economía Aplicada*, 23(2), 385-404. Cited on page 97.

[42] Cardenete, M.A. (2009) Los modelos de equilibrio general aplicado: una revisión de los principales campos de aplicación a nivel internacional, *Revista de economía mundial* 23, 73-100. Cited on pages 2, 3, 10 and 97.

[43] Cazcarro, I., Duarte, R., Sánchez Chóliz, J. (2010) Water consumption based on a disaggregated Social Accounting Matrix of Huesca (Spain), *Journal of Industrial Ecology*, 14(3), 496-511. Cited on pages 101, 104, 145, 148, 149, 150 and 167.

[44] Cazcarro, I., Duarte, R., Sánchez-Chóliz, J., Sarasa, C. (2011a) Water Rates and the Responsabilities of Direct, Indirect and End-Users in Spain, *Economic Systems Research*, 23(4), 409-430. Cited on pages 24, 54, 141 and 181.

[45] Cazcarro, I., Duarte, R., Sánchez-Chóliz, J., Sarasa, C. (2011b) Who Should Pay the Cost of Water? An Application to a Spanish Region. En Salander, L.M. and Alwell, D.N. (Eds.): *Food Production.* Nova Science Publishers, New York, 45-68. Cited on pages 24 and 54.

[46] Cazcarro, I., Duarte, R., Sánchez-Chóliz, J. (2013a) Multiregional Input−Output Model for the Evaluation of Spanish Water Flows, *Environmental Science & Technology*, 47 (21), 12275-12283. Cited on pages 247, 249, 258 and 259.

[47] Cazcarro, I., Duarte, R., Sánchez-Chóliz, J. (2013b) Downscaling the grey water footprints of production and consumption of the Spanish regions, Paper presented at the Spanish Input Output Conference in Seville, Spain, September 2013. Cited on pages 249 and 259.

[48] Decaluwé, B., Patry, A., Savard, L. (1999) When water is no longer heaven sent: comparative pricing analysis in a AGE model, Working Paper No. 9908, CRÉFA 99-05. Départment d'économique, Université Laval, Quebec. Cited on pages 96, 110, 244 and 255.

[49] Dechmi, F., Playán, E., Faci, J.M., Tejero, M. (2003) Analysis of an irrigation district in northeastern Spain. I. Characterisation and water use assessment, *Agricultural Water Management*, 61(2), 75-92. Cited on pages 38 and 66.

[50] Del Campo García, A. (1996) Las Comunidades de Regantes en España y su Federación Nacional *XIV Congreso Nacional de Riegos*. Aguadulce, Almería. Cited on pages 2 and 10.

[51] Dellink, R., Van Ierland, E. (2006) Pollution abatement in the Netherlands: A dynamic applied general equilibrium assessment, *Journal of Policy Modeling*, 28(2), 207–221. Cited on page 215.

[52] Dellink, R., Boruwer, R., Linderhof, V., Stone, K. (2011) Bio-economic modeling of water quality improvements using a dynamic applied general equilibrium approach, *Ecological Economics*, 71(15), 63-79. Cited on page 95.

[53] De Melo, J., Tarr, D. (1992) A general equilibrium analysis of US foreign trade policy, Cambridge, MA: The MIT Press. Cited on pages 116 and 124.

[54] De Schoutheete, D. (2012) Control of Carbon Emissions and Energy Fiscal

Reform in Spain. A Computable General Equilibrium Assessment. Ph.D. Thesis. Universitat Autònoma de Barcelona, Barcelona. Cited on pages 248 and 259.

[55] Dey, C., Berger, C., Foran, B., Foran, M., Joske, R., Lenzen, M., Wood, R. (2007) Household environmental pressure from consumption: An Australian environmental atlas. *Water wind art and debate: How environmental concerns impact on disciplinary research*, edited by G. Birch. Sydney, Australia: Sydney University Press. Cited on page 147.

[56] DGA. (2009) Anuario de Estadístico Agrario de Aragón 2008-2009. Departamento de Agricultura y Alimentación, Gobierno de Aragón, Zaragoza. Cited on pages 20, 50 and 122.

[57] DGA. (2011a) Superficies de cultivo PAC. Departamento de Agricultura y Alimentación, Gobierno de Aragón, Zaragoza. Cited on pages 18, 30, 39, 59, 67, 85, 86 and 87.

[58] DGA. (2011b) Superficies y producciones agrarias. Departamento de Agricultura y Alimentación, Gobierno de Aragón, Zaragoza. Cited on pages 41, 42, 68, 69, 91, 104, 122 and 146.

[59] CHE (1913-2007) Caudal en las estaciones de Aforo. Datos históricos. Confederación Hidrográfica del Ebro. Zaragoza. Cited on page 172.

[60] CHE (2008-2010) Anuario de Aforos. Confederación Hidrográfica del Ebro. Zaragoza. Cited on page 172.

[61] CHE (2011-2013) Sistema Automático de Información Hidrológica. Confederación Hidrográfica del Ebro. Zaragoza. Cited on page 172.

[62] Diao, X., Roe, T. (2003) Can a water market avert the ‘‘doublewhammy’’ of trade reform and lead to a ‘‘win–win’’ outcome*? Journal of Environmental Economics and Management*, 45(3), 708–723. Cited on page 96.

[63] Dietzenbacher, E., Lenzen, M., Los, B., Guan, D., Sancho, F., Suh, S., Yang, C. (2013) Input-Output Analysis: The next 25 years, *Economic Systems Research*, 25(4), 369-389. Cited on page 248 and 258.

[64] DMA (2000/60/CE) DIRECTIVA 2000/60/CE DEL PARLAMENTO EUROPEO Y DEL CONSEJO de 23 de octubre de 2000 por la que se establece un marco comunitario de actuación en el ámbito de la política de aguas. DO L 327 de 22.12.2000. Cited on pages 1, 24, 9, 54, 144 and 171.

[65] Dirkse, S.P., Ferris, M. (1995) The Path solver: A non-monotone stabilization

scheme for mixed complementarity problems, *Optimization Methods and Software*, 5(2), 123-156. Cited on page 100.

[66] Dixon, P., Parmenter, B., Sutton, J., Vincent, D. (1982) ORANI: Un modelo multisectoral de la economía australiana, Norte-Holanda. Cited on page 94.

[67] Dixon, P.B. (1990) A General Equilibrium Approach to Public Utility Pricing: Determining Prices for a Water Authority. *Journal of Policy Modelling*, 12, 745–767. Cited on page 149.

[68] Duarte, R., Sánchez-Chóliz, J., Bielsa, J. (2002) Water use in the Spanish Economy: an input-output approach, *Ecological Economics*, 43(1), 71-85. Cited on page 145.

[69] Durand-Lasserve, O., Pierru, A., Smeers, Y. (2010) Uncertain long-run emissions targets, CO_2 price and global energy transition: A general equilibrium approach, *Energy Policy*, 38(9), 5108-5122. Cited on page 97.

[70] European Commission (2008) Impact Assessment Accompanying the Package of Implementation Measures for the EU's Objectives on Climate Change and Renewable Energy for 2020 of the European Commission, {SEC(2008)85/3}, 23 January 2008, Brussels. Cited on page 216.

[71] Faci, J. M., Bensaci, A., Slatni, A., Playaán, E. (2000) A case study for irrigation modernisation: I. Characterisation of the district and analysis of water delivery records, *Agricultural Water Management*, 42(3), 313-334. Cited on pages 27, 40, 56 and 67.

[72] FAO. (1989) *Irrigation Water Management: Irrigation Scheduling. Training manual no. 4. Annex I.* FAO, Rome. Cited on pages 31 and 59.

[73] FAO. (2009) *Statistical Yearbook 2009*. FAO, Rome. Cited on page 20.

[74] Faust, A.K, Gonseth, C., Vielle, M., (2012) The economic impact of climate driven changes in water availability in Switzerland, *Conference Paper*, *EcoMod 2012*, Sevilla, Spain. Public Acces: GTAP Resource 3919. Cited on page 96.

[75] Federico, G. (2005) *Feeding the World. An Economic History of Agriculture, 1800-2000.* Princeton University Press, Princeton. Cited on pages 20 and 50.

[76] Feng, S., Li, L.X., Duan, Z.G., Zhang, J.L. (2007) Assessing the impacts of South-to-North Water Transfer Project with decision support systems, *Decision Support Systems*, 42(4), 1989– 2003. Cited on page 96.

[77] Ferris, M.C., Sinapiromsaran, K. (2000) Formulating and solving nonlinear

programs as mixed complementarity problems, *Optimization, Lectures Notes in Economics and Mathematical Systems*, 481, 132-148. Cited on page 100.

[78] Gámez, O. (2008) Modelo de Equilibrio General Computable para Nicaragua. *Documento de Trabajo*. Página web disponible en http://www.bcn.gob.ni/ Cited on page 94.

[79] García, I., Causapé, J.,Abrahao, R. (2009) Evolution of the efficiency and agro-environmental impact of a traditional irrigation land in the middle Ebro Valley (2001-2007), *Spanish Journal of Agricultural Research*, 7(2), 465-473. Cited on pages 21, 32, 33, 40, 51, 60, 61 and 68.

[80] Gerlagh, R., & van der Zwaan, B. C. C. (2003) Gross world product and consumption in a global warming model with endogenous technological change. *Resource and Energy Economics*, 25(1), 35–57. Cited on page 215.

[81] Gleick, P.H. (2000) The changing water paradigm: A look at twenty-first century water resources development, *Water International*, 25(1), 127-138. Cited on pages 21 and 50.

[82] Goodman, D.J. (2000) More Reservoirs or Transfers? A Computable General Equilibrium Analysis of Projected Water Shortage in the Arkansas River Basin, *Journal of Agricultural and Resource Economics*, 25(2), 698-713. Cited on pages 96 and 104.

[83] Gómez Gómez-Plana, A. (1999) GAMS/MPSGE: Un sistema para la resolución de modelos de equilibrio general aplicado, *Revista de Economía Aplicada*, 19(7), 171–183. Cited on page 100.

[84] Gómez Gómez-Plana, A. (2005) Simulación de políticas económicas: los modelos de equilibrio general aplicado, *Cuadernos Económicos de ICE*, 69, 197-217. Cited on pages 3, 11 and 100.

[85] Gómez, C.M., Tirado, D., Rey-Maquieira, J. (2004) Water exchanges versus water works: Insights from a computable general equilibrium model for the Balearic Islands, *Water Resources Research*, 40(10), 1-11. Cited on pages 96, 104, 110, 124, 149, 215, 244 and 255.

[86] González-Eguino, M. (2006) DANTE: Un mega dinámico para el control del cambio climático en España, *Working Paper series*: il. 22/06, University of the Basque Country. Cited on pages 100 and 215.

[87] González-Eguino, M. Dellink, R. (2006) Impact of climate policy on the Basque economy, *Economia Agraria y Recursos Naturales*, 6(12), 187-213.

Cited on page 108.

[88] González-Eguino, M. (2011) The importance of the design of market-based instruments for CO2 mitigation: An AGE analysis for Spain, *Ecological Economics*, 70(12), 2292-2302. Cited on page 108.

[89] Groot, E. (2006) Valoración financiera de los costes asociados al uso de agua de riego: el caso de Riegos del Alto Aragón (RAA) *Tesis del Master en Economía*. Universidad de Zaragoza, Zaragoza. Cited on page 104, 147, 150 and 152.

[90] Harberger, A.C. (1962) The Incidence of the Corporate Income Tax, *Journal of Policy Economy*, 70(3), 215-240. Cited on page 94.

[91] Harrison, G.W., Jensen, S. E.H, Pedersen, L.H, Rutherford, T. F. (Eds.) (2000) Using dynamic general equilibrium models for policy analysis. Amsterdam: North-Holland. Cited on page 215.

[92] Hermeling, C., Löschel, A., Mennel, T. (2013) A new robustness analysis for climate policy evaluations: A CGE application for the EU 2020 Targets, *Energy Policy*, 55, 27-35. Cited on page 98.

[93] Hertel, T.W. (1997) Global Trade Analysis: Modeling and Applications, *Cambridge University Press*, Cambridge. Cited on pages 94, 116 and 124.

[94] Hoekstra, A.Y., Hung, P.Q. (2002) Virtual water trade: a quantification of virtual water flows between nations in relation to international crop trade, *Value of Water Research Report Series*, 11. Cited on page 147.

[95] IAEST (2003) Explotaciones por régimen de tenencia en Aragón. Madrid. Cited on page 104.

[96] ICWE (1992) The Dublin Statement and Report of the Conference. International Conference on Water and the Environment: Development Issues for the 21st century. 26–31 January. Dublin. Cited on page 103.

[97] INE (1965-1989) *Anuarios Estadísticos*. Instituto Nacional de Estadística, Madrid. Cited on pages 20 and 50.

[98] INE (2002-2010) *Contabilidad Regional de España*. Instituto Nacional de Estadística, Madrid. Cited on page 123.

[99] Johansen, L. (1960) A Multisectorial Study of Economic Growth. Amsterdam: *North-Holland*. Cited on page 94.

[100] Jomini, P., Zeitsch, J.F., McDougall, R., Welsh, A., Brown, S., Hambley, J., Kelly, J., (1991) SALTER: A General Equilibirum Model of the World

Economy 1, Model Structure, Database and Parameters, Industry Commission, Canberra. Cited on pages 109 and 124.

[101] Junius, T., Oosterhaven, J. (2003) The solution of updating or regionalizing a matrix with both positive and negative entries, *Economic Systems Research*, 15(1), 87-96. Cited on page 150.

[102] Kehoe, T.J. (1996) Social Accounting Matrices and Applied General Equilibrium Models, Federal Reserve Bank of Minneapolis, *Working Paper*, 563. Cited on pages 101 and 149.

[103] Lau, M.I., Pahlke, A., Rutherford, T.F. (1997) Modeling Economic Adjustment: A Primer in Dynamic General Equilibrium Analysis, Working paper No 97-27, University of Colorado, Colorado, USA. Cited on page 120.

[104] Lecina, S., Isidoro, D., Playán, E., Aragüés, R. (2010a) Irrigation modernization and water conservation in Spain: The case of *Riegos del Alto Aragón, Agricultural Water Management, 97(10), 1663-1675.* Cited on pages 35 and 63.

[105] Lecina, S., Isidoro, D., Playán, E., Aragüés, R. (2010b) *Análisis del regadío II: ¿por qué se moderniza? La productividad del regadío y el ahorro de agua.* Hoja Técnica 02/2010. Centro de Investigación y Tecnología Agroalimentaria de Aragón, Zaragoza. Cited on pages 23 and 52.

[106] Lenzen, M., Foran, B. (2001) An input-output analysis of Australian water usage, *Water Policy*, 3(4), 321-340. Cited on page 144.

[107] Lenzen, M., Murray, J., Sack, F., Wiedman, T. (2007) Shared producer and consumer responsibility. Theory and practice, *Ecological Economics*, 61(1), 27-42. Cited on pages 6, 13, 145, 249 and 259.

[108] Lenzen, M. (2009) Understanding virtual water flows: A multiregion input-output case study of Victoria, *Water Resources Research*, 45(9), W09416. Cited on page 145.

[109] Lenzen, M., Peters, G. (2010) How city dwellers affect their resource hinterland. A spatial impact study of Australian households, *Journal of Industrial Ecology*, 14(1), 73-90. Cited on pages 144, 145 and 147.

[110] Llop, M., Ponce-Alifonso, X. (2012) Agriculture, technological change and environmental sustainability: Looking for a win-win water policy strategy, Documents de treball del departament d'economia – CREIP, Working Papers, 17. Universitat Rovira i Virgili. Tarragona. Cited on pages 96 and 103.

[111] Löfgren, H., Lee Harris, R., Robinson, S. (2002) A Standard Computable General Equilibrium (CGE) Model in GAMS, *International Food Policy Research Institute*. Washington D.C., USA. Cited on pages 4, 94, 98, 101, 106, 132, 133, 134, 137 and 150.

[112] Löfgren, H. and Díaz-Bonilla, C. (2010) MAMS: An Economy-wide Model for Analysis of MDG Country Strategies –an application to Latin America and the Caribbean. *Public Policies for Human Development: achieving the millennium development goals in Latin America*, edited Basingstoke, Hampshire [u.a.]: Palgrave Macmillan, ISBN 9780230247765, p. 71-126. Cited on pages 11 and 94.

[113] Lofting, E.M., McGauhey. P.H. (1968) Economic valuation of water. An input-output analysis of California water requirements, *Water Resources Center*. Cited on page 145.

[114] Maestu, J., Villar, A. (2007) El análisis económico en la Directiva Marco del Agua y su papel en el proceso de planificación hidrológica, *Ingeniería y Territorio*, 80, 48-57. Cited on pages 2 and 10.

[115] Mainar, A., (2010) Consumption Patterns and Environmental Impacts of the CO2, Emissions, An Approximation from Input-Output Analysis. Doctoral thesis. University of Zaragoza; Zaragoza. Cited on pages 124, 144 and 169.

[116] Mansur, A.H. and Whalley, J. (1984) Numerical Specification of Applied General Equilibrium Models: Estimation, Calibration and Data. En Scarf, H. E. and J.B. Shoven (eds.) *Applied General Equilibrium Analysis* Cambridge University Press, Cambridge. Cited on page 101.

[117] MAPA (2002) Resultados Técnico-Económicos de Explotaciones Agrícolas de Aragón, Ministry of Agriculture, Fisherires and Food, Madrid. Cited on page 104.

[118] MAPA (2006) Hechos y cifras de la agricultura, la pesca y alimentación en España. 8º Edición. Ministry of Agriculture, Fisheries and Food. Madrid. Cited on pages 1 and 9.

[119] MAPA (2007) Encuesta sobre Superficies y Rendimientos de Cultivos *ESYRCE*. Ministry of Agriculture, Fisheries and Food. Madrid. Cited on pages1 and 9.

[120] MAPA (2009) Anuario de Estadística Agraria 2009, datos de SAU del 2007. Ministry of Agriculture, Fisheries and Food. Madrid. MAPA Cited on pages 1

and 9.

[121] Markusen, J. (2014) Markusen´s guides. http://spot.colorado.edu/~markusen/ Cited on page 129.

[122] Markusen, J. and Rutherford, T. (2004) MPSGE: A User´s Guide *Lecture Notes, UNSW Workshop*, University of Colorado; Boulder. Cited on pages 4, 12 and 95.

[123] MARM (2001-2008) *Anuario Estadístico*. Ministry of Agriculture, Food and Environment, Madrid. Cited on pages 42 and 69.

[124] MARM (2001-2009) *Resultados técnico-económicos de explotaciones agrícolas de Aragón.* Ministry of Agriculture, Food and Environment, Madrid. Cited on pages 43, 70

[125] MARM. (2001) *Evaluación de un perímetro de riego en la zona regable del Cinca (Huesca).* Ministry of Agriculture, Food and Environment, Madrid. Cited on pages 31, 34, 60 and 63.

[126] MARM. (2008) *Plan Nacional de Regadíos. Horizonte 2008.* Ministry of Agriculture, Food and Environment, Madrid. Cited on pages 20 and 50.

[127] MARM. (2010) *Anuario de Estadística Agroalimentaria 2010*. Ministry of Agriculture, Food and Environment, Madrid. Cited on pages 20 and 50.

[128] Martínez-Cob, A., Faci, J.M., Bercero, A. (1998) *Evapotranspiración y necesidades de riego de los principales cultivos en las Comarcas de Aragón*. Institución Fernando el Católico, Zaragoza. Cited on pages 23, 28, 29, 53 and, 58.

[129] McGregor, P., Partridge, M., Rickman, D. (2010) Innovations in Regional Computable General Equilibrium (CGE) Modelling, *Regional Studies*, 44(10), 1307-1310. Cited on pages 3 and 10.

[130] McKinney, D., Cai, X., Rosegrant, M.W., Ringler, C., Scott, C.A., (1999) Modeling Water Resources Management at the Basin Level: Review and Future Directions, *International Water management Institute*, Colombo. (SWIM Paper 6, 71). Cited on page 99.

[131] MIMAN (2007) El agua en la economía española: Situación y perspectivas. Informe integrado del análisis económico de los usos de agua. Artículo 5 y anejos II y III de la Directiva Marco del Agua. Ministerio de Medio Ambiente, Madrid. Cited on pages 1 and 9.

[132] MMA (Ministerio de Medio Ambiente) (2000). Plan Hidrológico Nacional.

Análisis de sistemas hidráulicos. Ministerio de Medio Ambiente. Madrid. Cited on page 172.

[133] Munksgaard, J., Pedersen, K. (2001) CO_2 accounts for open economies: producer or consumer responsibility? *Energy Policy*, 29(4), 327-334. Cited on pages 6, 13 and 145.

[134] NVIRP (2011) Northern Victoria Irrigation Renewal Project. Australia. Internet site www.nvirp.com.au. Cited on page 147.

[135] OECD (2003) Effects of Quantitative Constraints on the Degree of Decoupling of Crop Support Measures, OECD Document AGR/CA/APM(2002)12/FINAL Cited on pages 105 and 124.

[136] O'Ryan, R., de Miguel, C.J., Miller, S. (2003) Ensayo sobre Equilibrio General Computable: Teoría y Aplicaciones *Universidad de Chile*, Santiago de Chile. Cited on pages 97 and 99.

[137] Ostrom, E. (2000) El gobierno de los bienes comunes. La evolución de las instituciones de acción colectiva, *Fondo de Cultura Económica*, Ciudad de México. Cited on pages 2 and 10.

[138] Paavola, J., Hubacek, K. (2014). Ecosystem services, governance and stakeholder participation: an introduction. *Ecology & Society*, 18(4): 42. Cited on pages 249 and 260.

[139] Paltsev, S.V. (2000) Moving from Static to Dynamic General Equilibrium Economic Models (Notes for a beginner in MPSGE) Department of Economics, University of Colorado, Colorado. Cited on pages 100, 118 and 119.

[140] Partridge, M., Rickman, D. (2010) Computable General Equilibrium (CGE) Modelling for Regional Economic Development Analysis, *Regional Studies*, 44(10), 1311-1328. Cited on pages 3 and 10.

[141] Peters, G.P., Hertwich, E.G. (2006) Pollution embodied in trade: the Norwegian case, *Global Environmental Change*, 16(4), 379-389. Cited on pages 6, 13 and 145.

[142] Philip, J.M. (2009) The EPA between Ghana and the EU: Quantitative analysis based on recursive and intertemporal dynamic CGE models. Seminar, Aix-Marseille University, Aix-en-Provence, France. Cited on page 127.

[143] Pinilla, V. (2006) The development of irrigated agriculture in twentieth-century Spain: a case of study of the Ebro basin, *Agricultural History Review*, 54(1),

122-141. Cited on pages 38 and 66.

[144] Pinilla, V. (2008) *Gestión y usos del agua en la Cuenca del Ebro en el siglo XX*. Prensas Universitarias de Zaragoza, Zaragoza. Cited on pages 20, 21, 50, 174 and 175.

[145] Playán, E., Slatni, A., Castillo, R, Faci, J.M., (2000) A case study for irrigation modernisation. II. Scenario analysis, *Agricultural Water Management*, 42(3), 335-354. Cited on pages 21, 27, 32, 51, 56 and 60.

[146] Pratt, S., Blake, A., Swann, P. (2013) Dynamic general equilibrium model with uncertainty: Uncertainty regarding the future path of the economy, *Economic Modelling*, 32, 429-439. Cited on pages 97, 98 and 216.

[147] Prell, C., Hubacek, K., Reed, M. (2009) Stakeholder analysis and social network analysis in natural resource management. *Society and Natural Resources*, 22(6), 501-518. Cited on pages 249 and 260.

[148] Psaltopoulos, D., Balamou, E., Skuras, D., Ratinger, T., Sieber, S. (2011) Modelling the impacts of CAP Pillar 1 and 2 measures on local economies in Europe: Testing a case study-based CGE-model approach, *Journal of Policy Modeling*, 33(1), 53-69. Cited on pages 4 and 11.

[149] Radwan, A., Gil, J.M., Ben, M., Serra, T. (2009) Food Safety Information and Meat Demand in Spain. Contributed. Paper prepared for presentation at the International Association of Agricultural Economists Conference, in Beijing, China August, 16–22. Cited on pages 114 and 169.

[150] Ramos, A., Sánchez, P., Ferrer, J.M., Barquín, J., Linares, P. (2010) Modelos matemáticos de optimización, Universidad Pontificia de Comillas, Madrid. Cited on page 100.

[151] Reed, M.S., Bonn, A., Broad, K., Burgess, P., Burt T.B., Fazey, I.R., Hubacek, K., Nainggolan, D., Quinnm, C.H., Roberts, P., Stringer, L.C., Thorpe, S., Walton, D.D., Ravera, F., Redpath, S. (2013). Participatory scenario development for environmental management: a methodological framework. *Journal of Environmental Management*, 128(15), 345-362. Cited on pages 249 and 260.

[152] Robinson, J. (1962) *Essays in the Theory of Economic Growth*, London: Macmillan. Cited on back cover.

[153] Robinson, S. (1991) Macroeconomics, Financial Variables, and Computable General Equilibrium Models, World Development, 19, No. 11, 1509-1525.

Cited on page 99.

[154] Robinson, S. (2006) Macro models and multipliers: Leontief, Stone, Keynes, and CGE models. In book: *Poverty, Inequality and Development: Essays in Honor of Erik Thorbecke*, Chapter: 11, Publisher: Springer Science, Editors: Alain de Janvry, Ravi Kanbur, 205-232. Cited on pages 95, 98 and 116.

[155] Robinson, S., Gueneau, A. (2013) CGE-W: an Integrated Modeling Framework for Analyzing Water-Economy Links Applied to Pakistan, Conference Paper presented at the 16th Annual Conference on Global Economic Analysis, Shanghai, China. Cited on page 96.

[156] Roux, D. (2006) Los premios nobel de economía: 1969-2005 *Akal*. Cited on page 93.

[157] Rutherford, T.F. (1999) Applied general equilibrium modeling with MPSGE as a GAMS subsystem: An overview of the modeling framework and syntax. *Computational Economics*, 14, 1-46. Cited on page 95.

[158] Rutherford, T.F., Meeraus, A. (2005) Mixed complementarity formulations of stochastic equilibrium models with recourse. GOR Workshop ‘‘Optimization under Uncertainty’’ Bad Honnef, Germany, October20–21. URL /http://www.gams.com/presentations/present_recourse.pdfS. Cited on page 230.

[159] Sala-i-Martín, X. (2005) Apuntes de crecimiento económico *Antoni Bosch Editor*. Cited on page 95.

[160] Sánchez-Chóliz, J. (2005). Los recursos hídricos del Ebro y el Plan Hidrológico Nacional. Universidad de Zaragoza, Zaragoza. Cited on pages 172 and 173.

[161] Sánchez-Chóliz, J., Duarte, R. (2006) Mirando al futuro con esperanza. *Riegos del Alto Aragón. Impacto económico y social 1953-2003*, 8, 237-260. Cited on pages 25, 27, 54 and 56.

[162] Sánchez-Chóliz, J. (2007) *Análisis económico del uso del agua. Esquema de temas importantes. Plan Hidrológico (2007).* Universidad de Zaragoza, Zaragoza. Cited on pages 45 and 72.

[163] Sánchez-Chóliz, J., Sarasa, C. (2011) Análisis de los recursos hídricos del Alto Aragón durante la primera década del siglo XXI: demanda, eficiencia y productividad. Riegos del Alto Aragón, Huesca, España. Cited on page 18.

[164] Sánchez-Chóliz, J., Sarasa, C. (2013) Análisis de los recursos hídricos de *Riegos del Alto Aragón* (Huesca) en la primera década del siglo XXI. *Economía Agraria y Recursos Naturales*, 13(1), 95-122. Cited on pages 17, 18

and 196.

[165] Sánchez-García, M.A. (2005) Modelos de equilibrio general aplicado: un enfoque microeconómico para hogares rurales, *Reflexiones económicas. Instituto de Investigaciones económicas y sociales*, Universidad Rafael Landívar, Guatemala. Cited on pages 97 and 99.

[166] Sanromá, E., Ramos, R. (1999) Interprovincial Wage Differences in Spain: a Microdata Analysis for 1990, *Jahrbuch für Regionalwissenschaft*, 19, 33-54. Cited on pages 248 and 259.

[167] Savenije, H., van der Zaag, P. (2002) Water as an Economic Good and Demand Management *Paradigms with Pitfalls,* International Water Resources Association, *Water International*, 27(1), 98–104. Cited on page 103.

[168] Scarf, H. and Hansen, T. (1973) The computation of economic equilibria, *New Haven: Yale University Press*. Cited on page 94.

[169] Schoengeld, K., Zibelman, D. (2007) The economics of water, irrigation, and development. En Evenson, R.E. y Pingali, P. (Eds.): *Handbook of Agricultural Economics*. North Holland, Amsterdam. Cited on pages 21 and 50.

[170] Seung, C.K., Harris, T.R., McDiarmid, T.R., Shaw, W.D. (1998) Economics impacts of water reallocation: a CGE analysis for the Walker River Basin of Nevada and California, *Journal of Regional Analysis and Policy*, 28, 13-34. Cited on pages 96, 112, 124, 244 and 255.

[171] Shoven, J. B., Whalley, J. (1992) Applying General Equilibrium. *Cambridge Univ. Press*. Nueva York. Cited on page 145.

[172] Silvestre, J., Clar, E. (2010) The demographic impact of irrigation projects: a comparison of two case studies of the Ebro basin, Spain, 1900-2001, *Journal of History Geographic*, 36(3), 315-326. Cited on pages 21, 38, 51 and 66.

[173] Strzepek, K.M., Yohe, G.W., Tol, R.S.J., Rosegrant, M.W. (2008) The value of the high Aswan Dam to the Egyptian economy, *Ecological Economics*, 66(1), 117-126. Cited on page 96.

[174] Tarp, H., Tarp, F. (2002) A Standard World Bank-IMPF Simulation Framework with CGE Features, Chapter 13 in Facing the Development Challenge in Mozambique in Tarp, H., Arndt, C., Tarp, H., Robinson, S., Heltberg, R.Research Report 126, International Food Policy Research Institute, Washington, D.C. Cited on page 99.

[175] Taylor, L. (1990) Structuralist CGE Models, in Lance Taylor (ed.), Socially

Relevant Policy Analysis: Structuralist Computable General Equilibrium Models for the Developing World, Cambridge, MA: The MIT Press. Cited on page 95.

[176] Taylor, L. (2004) Reconstructing Macroeconomics: Structuralist Proposals and Critiques of the Mainstream. Cambridge, MA: Harvard University Press. Cited on page 95.

[177] Tedeschi, A., Beltrán, A., Aragüés, R. (2001) Irrigation management and hydrosalinity balance in a semi-arid area of the middle Ebro river basin (Spain), *Agricultural Water Management*, 49(1), 31-50. Cited on pages 21, 32, 34, 51, 60 and 62.

[178] Tirado, D.B, Gómez, C.M., Lozano, J. (2006) Un modelo de equilibrio general aplicado a Baleares: análisis económico de la reasignación intrasectorial del agua para uso agrícola, *Estudios Agrosociales y Pesqueros*, 209, 75-109. Cited on page 96.

[179] Turner, K., Gilmartin, M., McGregor, P.G., Kim Swales, J.K. (2008) The added value from adopting a CGE approach to analyse changes in environmental trade balances, SIire Discussion Paper, University of Strathclyde, Glasgow. Cited on pages 247 and 258.

[180] Turner, K, Lange, I., Lecca, P., Ha, S.J. (2012a) Econometric estimation of nested production functions and testing in a computable general equilibrium analysis of economy-wide rebound effects. Stirling Economics Discussion Paper 2012-08, University of Stirling, Division of Economics. Cited on pages 248 and 258.

[181] Turner, K., Munday, M., McGregor, P., Swales, K. (2012b) How responsible is a region for its carbon emissions? An empirical general equilibrium analysis, *Ecological Economics*, 76, 70–78. Cited on pages 249 and 259.

[182] Van Heerden, J.H., Blignaut., J., Horridge, M. (2008) Integrated water and economic modelling of the impacts of water market instruments on the South African economy, *Ecological Economics*, 66, 105-116. Cited on pages 96, 216, 244 and 255.

[183] Velázquez, E., Cardenete, M.A., Hewings, G.J.D. (2006) Precio del agua y relocalización sectorial del recurso en la economía andaluza. Una aproximación desde un modelo de equilibrio general aplicado, *Estudios de Economía Aplicada*, 24, 3-13. Cited on pages 96, 145, 149, 215, 244 and 255.

[184] Villaverde, J. (1999) Dispersión y Flexibilidad Regional de los Salarios en España, *Papeles de Economía Española*, 80, 171-84. Cited on pages 248 and 259.

[185] Walras, L. (1874) Elementos de Economía Política Pura, *Alianza Editorial*, Madrid. Cited on page 93.

[186] Wiedmann, T. (2009) A review of recent multi-region input–output models used for consumption based emission and resource accounting. *Ecological Economics*, 69(2), 211–222. Cited on pages 247 and 258.

[187] Wiedmann, T., Barrett, J. (2013) Policy-Relevant applications of Environmentally Extended MRIO Databases- Experiences from the UK, *Economic Systems Research*, 25(1), 143-156. Cited on pages 247 and 258.

[188] Yang, J., Huang, J., Qiu, H., Rozelle, S., Sombilla, M.A. (2009) Biofuels and the Greater Mekong Subregion: Assessing the impacts on prices, production and trade. *Applied Energy*, 86(1), 37–46. Cited on page 105.

[189] Zubieta, E. (2010) Transformación de secano a regadío de 224,63 hectáreas en el término municipal del Murillo el Cuende (Navarra). Universidad Pública de Navarra, Pamplona. Cited on pages 120 and 139.

Final Appendix

Table FA1. **SAM accounts**

C1	Cereals and legumes (irrigated land)
C2	Industrial crops (irrigated land)
C3	Fruit and vegetables (irrigated land)
C4	Olives and vineyards (irrigated land)
C5	Non-irrigated agriculture
C6	Livestock
C7	Energy products
C8	Water
C9	Minerals and metals
C10	Minerales and non-metals products
C11	Chemicals
C12	Mineral products, machinery and transport material
C13	Agri-food industry
C14	Manufactures
C15	Rubber, plastics and others
C16	Construction and engineering
C17	Hotels and restaurants
C18	Rest of services
F1	Labor factor
F2	Capital factor
F3	Water factor
F4	Land factor
H	Households
S	Societies/firms
G	Government
ITX	Institutional taxes
FTX	Factor taxes
VATX	Value-added taxes
R1	Rest of Spain
R2	Rest of European Union
R3	Rest of World
S-I	Savings-Investments

Source: Own work.

Table FA2. **SAM 2002 Huesca**

		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
Productive Activities	C1	5,460					3,872	0.023	0.001					63,243	1,562		0.925	3,015	0.485
	C2		5,762				7,264	0.056	0.001					27,468	0.666		0.008	0.490	0.930
	C3			0.713				0.006	0.002					89,704	2,584		2,303	1,809	0.134
	C4				0.214									21,746	0.310		0.184	0.888	1,374
	C5					12,324	9,141		0.001					80,906	4,160		0.003	0.635	0.627
	C6	0.420	0.308	0.020	0.323	1,252	1,924							163,956	0.118			0.734	3,189
	C7	0.333	1,390	2,897	0.149	1,653	5,371	29,406	0.369	0.511	5,643	12,328	6,306	7,802	2,980	1,193	6,702	7,453	36,161
	C8	0.129	0.706	1,162	0.041	0.423	0.021	0.007	0.002	0.015	0.013	0.057	0.048	0.078	0.006	0.006	0.058	0.314	0.584
	C9							0.408		0.574	6,450	0.388	1,375	0.027	0.000		6,597		0.056
	C10							0.073		0.078	22,580	0.007	2,787	4,550	0.075	0.472	138,806	1,671	2,309
	C11	2,370	12,172	31,246	1,015	11,086	48,416	1,818	0.302	1,250	8,610	299,536	47,496	38,854	25,272	50.985	27,581	3,441	79,370
	C12	0.488	2,147	4,213	0.159	2,095	7,613	4,419	0.234	1,242	10,968	14,765	322,510	6,859	4,246	12,523	112,281	1,587	48,920
	C13	13,214	9,815	25,831	22,304	32,262	86,502					1,508		182,279	4,149			161,171	8,054
	C14	0.002	0.001	0.024			0.023	0.627	0.057	0.180	1,304	2,059	3,528	8,231	46,753	11,188	11,808	1,523	25,073
	C15	0.156	0.256	0.780	0.048	0.347	1,327	0.018	0.028	0.111	0.853	7,548	22,638	10.051	2,544	12,069	15,319	0.681	9,191
	C16	0.459	1,907	4,034	0.358	2,365	7,630	13,304	0.674	0.546	3,455	6,070	8,060	2,209	2,093	0.913	474,755	6,990	186,395
	C17	0.019	0.095	0.178	0.005	0.060	0.299	0.557	0.036	0.037	0.571	2,121	4,486	2,266	0.654	0.896	10.154	2,621	30.614
	C18	1,675	9,581	10,436	0.477	6,008	10.765	11,329	0.925	3,729	27,555	57,446	100,358	124,912	39,346	20,774	142,609	40.864	632,509
Factors	F1	0.098	0.449	5,947	0.214	0.918	6,377	17,491	0.924	2,290	32,325	65,302	157,335	87,270	43,463	28,469	247,042	65,971	939,795
	F2	5,156	15,229	53,692	5,036	34,496	94,102	41,909	0.151	2,591	23,637	2,371	87,446	77,074	31,248	9,952	184,220	236,432	815,346
	F3	9,548	8,212	2,671	0.253		20,692	19,046	1,122	0.061	0.140	40,357	0.674	0.895	0.536	5,677	0.301	1,466	5,617
	F4	1,208	0.580	0.140	0.018	1,013													
Agents	H																		
	S																		
	G																		
TAXES	ITX																		
	FTX																		
	VTX	-2,976	1,107	0.759	-0.013	-1,023	-1,053	-0.432	0.249	0.573	4,095	14,926	4,850	-12,400	1,545	0.744	20,969	14,124	83,930
Foreign sectors	R1	24,360	0.458	41,969	0.003	52,533	56,046	68,167		4,514	78,824	395,812	310,634	362,613	94,119	47,692	0.409	11,723	212,777
	R2	27,581	0.318	0.373	0.002	41,239	48,333	4,393		0.201	4,277	141,151	103,357	55,424	19,321	11,930		0.355	47,216
	R3	0.010		0.079		0.148	0.116	1,285		1,626	1,251	41,302	30.243	16,217	5,653	3,491		0.037	1,541
	S-I																		
	TOTAL	89,712	70,494	187,162	30,604	199,201	414,781	213,909	5,078	20,130	232,551	1.105,068	1.214,131	1.422,235	333,402	218,974	1.403,034	565,997	3.172,196

		F1	F2	F3	F4	H	S	G	ITX	FTX	VTX	R1	R2	R3	S-I	TOTAL
Productive Activities	C1					8,521						1,814	0.411		0.378	89,712
	C2					2,328						20,808	4,711		0.003	70,494
	C3					5,031						65,172	14,756	4,001	0.941	187,162
	C4					2,598						2,621	0.593		0.075	30,604
	C5					16,527						60,331	13,660	0.883	0.002	199,201
	C6					3,204						204,856	30.121	0.726	3,631	414,781
	C7					45,257						39,089	0.181	0.062	0.674	213,909
	C8					1,255						0.000	0.050	0.104		5,078
	C9					0.020						3,586	0.481	0.118	0.051	20,130
	C10					1,831						56,749	0.419	0.143		232,551
	C11					62,935		112,574				126,190	83,182	28,379	0.988	1,105,068
	C12					36,926		0.627				362,367	141,977	48,438	66,526	1,214,131
	C13					265,332						325,662	211,137	72,032	0.985	1,422,235
	C14					76,627						124,220	14,296	4,878	1,001	333,402
	C15					34,255						79,589	9,026	3,079	9,060	218,974
	C16					42,050						0.415	0.250	0.098	638,004	1,403,034
	C17					501,199		0.958					5,861	2,310		565,997
	C18					819,794		810,636				175,966	51,078	11,078	62,345	3,172,196
Factors	F1															1,701,679
	F2															1,720,091
	F3															117,268
	F4															2,959
Agents	H	1,701,679	866,092	117,268	2,959		198,298	576,804					-5,290	-3,321		3,454,490
	S		737,484			107,058		119,779					-36,399	-18,895		909,028
	G								1,457,665	116,515	129,975		58,512	25,446		1,788,113
TAXES	ITX					1,218,913	238,752									1,457,665
	FTX		116,515													116,515
	VTX															129,975
Foreign sectors	R1															1,762,655
	R2														93,540	599,012
	R3														76,558	179,559
	S-I					202,830	471,977	166,735				113,221				954,763
	TOTAL	1,701,679	1,720,091	117,268	2,959	3,454,490	909,028	1,788,113	1,457,665	116,515	129,975	1,762,655	599,012	179,559	954,763	

Value: Million euros.
Source: Own work based Cazcarro *et al*. (2010) [X].

“Que la ilusión continúe,

y sigamos aprendiendo y creciendo”